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LAMINAR FORCED CONVECTION TO MIXTURES OF INERT GASES IN PARALLEL PLATE DUCTS

Prepared by

D. M. McEligot, M. F. Taylor and F. Durst

Research Sponsored by

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Heat transfer and wall friction parameters were obtained numerically to demonstrate the effects of mixture composition and gas property variation for heating or cooling in regenerative heat exchangers; the situation is modelled by laminar flow through short ducts with constant wall heat flux. For design predictions accounting for the effects of property variation, the property ratio method is better than the film temperature method for heat transfer while the latter method is preferable for apparent wall friction--providing that the present definitions of the non-dimensional parameters be employed.

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Interim Report*

LAMINAR FORCED CONVECTION TO MIXTURES OF INERT GASES IN PARALLEL PLATE DUCTS

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ABSTRACT

Mixtures of inert gases can be used to improve performance in closed gas turbine cycles. In the present work, heat transfer and wall friction parameters have been obtained numerically to demonstrate the effects of mixture composition and gas property variation for heating or cooling in regenerative heat exchangers of such cycles; the situation is modelled by laminar flow through short ducts with constant wall heat flux. For design predictions accounting for the effect of property variation, it is found that the property ratio method is better than the film temperature method for heat transfer while the latter method is preferable for apparent wall friction - with the proviso that the present definitions of the non-dimensional parameters be employed.

INDEX

NOMENCLATURE

a, b, c	exponents for temperature-dependence of properties, equation (6)
c_p	specific heat at constant pressure
D_h	hydraulic diameter (twice plate spacing)
G	average mass flux
g_c	dimensional constant
h	heat transfer coefficient
k	thermal conductivity
L	length
p	pressure
p, q	exponents for property ratio method, equations (11) and (15)
T	absolute temperature
u	axial velocity
V_b	bulk velocity
x	axial coordinate

<u>Greek symbols</u>

$\epsilon/\kappa, \sigma$	force constants in Lennard-Jones (6-12) potential
μ	absolute viscosity
ρ	density

<u>Dimensionless quantities</u>

f, f_{ap}	apparent friction factor based on one-dimensional apparent wall shear stress, e.g., equation (13); f_a, lengthwise mean apparent friction factor
$\bar{H}$	enthalpy, $(H - H_o)/(c_{po}T_o)$
L^+	length for velocity boundary layer, $4L/(D_h Re)$
L^*	length for thermal boundary layer, $4L/(D_h RePr)$
Nu	Nusselt number, hD_h/k

$\bar{p}$	pressure, $2g_c \rho_o p/G^2$
Pr	Prandtl number, $c_p \mu/k$
Q^+	wall heat flux, $q''_w D_h/(k_o T_o)$
Re	Reynolds number, GD_h/μ; Re_x, based on axial coordinate $\rho V_{bo} x/\mu$
v^+	transverse velocity, $(1/4)vRe/V_{bo}$
x^+	axial coordinate for velocity boundary layer, $4x/(D_h Re)$
x^*	axial coordinate for thermal boundary layer, $4x/(D_h RePr)$
$\bar{y}$	transverse coordinate, y/D_h

Subscripts

a	overall average or mean value (lengthwise)
b	properties evaluated at bulk temperature
cp	based on constant property idealizations
e	in entry region
f	based on film temperature, $(T_w + T_b)/2$
fd	fully established or asymptotic value
m	lengthwise mean value
ref	reference
w	properties evaluated at wall temperature
x	properties evaluated at local temperature
O	inlet conditions

The circumflex (^) represents non-dimensionalization with respect to the value of the quantity at the inlet, e.g., $\hat{\rho} = \rho/\rho_o$.

1. INTRODUCTION

The closed Brayton cycle, or gas turbine cycle, has been suggested as an efficient, compact, versatile system for power plant and propulsion applications [1, 2] . With thermodynamic cycle studies, Bammert and Klein [3] showed that considerable savings in the total costs of a gas turbine cycle can be achieved by mixing helium with a heavier gas; the increase in density reduces the size of the turbomachines while the reduction in thermal conductivity increases the size of the heat exchangers so that an optimum occurs at an intermediate molecular weight. Approximate calculations indicate that when the heavier gas is another noble gas further improvements in heat transfer performance are possible, compared to pure gases at the same pressure, temperature and molecular weight [4] . However, the gaseous data and correlations for heat exchangers have been obtained with pure gases, primarily air, with negligible variation of the transport properties. Whether such results can be applied for mixtures of inert gases with temperature-dependent properties is a basic question which the present paper attacks.

In gas turbine cycles the regenerative heat exchanger is typically constructed of parallel plates, with short fins attached forming additional parallel surfaces. Consideration of the heat transfer performance versus pumping power requirements of these heat exchangers usually results in design for operation in the laminar or transitional flow regime. For laminar flow heat exchangers, the streamwise length of the fins is shortened in order to take advantage of the increased heat transfer coefficient of developing boundary layers by continually reinitiating the boundary layer. The thermal boundary condition is an approximately constant wall heat flux. As a guide to the effects of mixture composition and property variation in such geometries, the present paper - for a first objective - investigates the simultaneous development of laminar thermal and velocity boundary layers in the entry region of parallel plate ducts.

The following section briefly discusses related work which can be extended to provide improved guidance to the designer of regenerative heat exchangers for mixtures of noble gases. Section 3 summarizes pertinent knowledge of their transport properties and demonstrates the generalizations possible to reduce the analytical task. Since the consequent governing equations are nonlinear and coupled, they are solved numerically as outlined in section 4. The results of interest in design-lengthwise mean parameters - are presented in

section 5 : first, the effect of composition at low heating rates and, then, the effects that the temperature-dependence of the transport properties cause on the heat transfer parameters and the wall friction parameters, separately. Finally, the major conclusions are reiterated in the last section.

2. PREVIOUS WORK

In preliminary design studies for closed gas turbine systems, Vanco [4] estimated relative heat transfer coefficients and pressure drop for binary mixtures of the inert gases with geometry held constant. For heat transfer he employed a constant property version of the Sieder-Tate relationship suggested by Kern [5]

$$Nu_m = 1.86 \ Re^{1/3} Pr^{1/3} (D/L)^{1/3} = 2.95 \ (L^*)^{-1/3} \qquad (1)$$

This relation is essentially a thermal entry correlation of the Leveque form [6] which strictly applies only for a linear velocity profile as in the wall region of a fully established flow. With long tubes the Nusselt number should become constant rather than tending to zero as in the above relationship. For pressure drop calculations, Vanco used the friction factor for fully developed flow. His approach is still prevalent in industrial design of laminar flow heat exchangers.

As shown later, one of the main effects of varying mixture composition is to vary the Prandtl number. If the velocity profile is fully established before heating commences, the function $Nu_m(L^*)$ should depend on geometry and thermal boundary condition and be independent of Pr since the non-dimensional variables can be defined so that Pr does not appear in the governing energy equation or its boundary conditions [7]. Since thermal and shear boundary layers grow at different rates when the Prandtl number is not unity, the solutions to the simultaneous entry problem will vary with Prandtl number. In a numerical analysis Hwang and Fan [8] have shown this variation to be significant at low values of L^* for constant wall heat flux and constant fluid properties. For the comparable constant wall temperature problem, Schlünder [9] suggests applying the Pohlhausen solution in the immediate entry as

$$Nu_{m,e} = 0.664 \ (L^*)^{-1/2} Pr^{-1/6} \qquad (2)$$

in continuous functions of the form

$$Nu_m = \sqrt[n]{Nu_{td}^n + Nu_{m,e}^n} \qquad (3)$$

for design computation.

Schade and McEligot [10] developed a numerical solution to examine the effect of air property variation for the simultaneous entry problem with strong heating or cooling applied to two parallel plates. They concluded that the local Nusselt number increases slightly and local friction factors increase severely with heating. To engineers accustomed to constant property analyses, the occurance of a large change in friction factor and pressure drop while the Nusselt number is changing only slightly might be surprising. Schade and McEligot showed that such comparisons are sensitive to the choice of the temperature at which the properties in the non-dimensional parameters are evaluated and that use of the constant property idealization can lead to either dangerous or conservative design, depending on the application.

For the heat exchanger applications, designers employ mean parameters and resort to empirical methods to correct for fluid property variation [11] . The two most common schemes are the reference temperature method and the property ratio method [12] . Based on experiment and approximate analysis, Kays recommends exponents for the latter method for various geometries and fluids. However, despite the ready availability of appropriate numerical methods for laminar flows for over a decade [13], these empirical correlations have not been refined and the question as to which is the more accurate method has not been answered. Accordingly, a <u>second objective</u> of the present paper is to examine this question and, if possible, to improve the exponents used in the property ratio method - for the parallel plate geometry and constant wall heat flux.

3. TRANSPORT PROPERTIES OF NOBLE GAS MIXTURES

While real gas properties can be employed in the numerical analysis in tabular or equation form directly, it is advantageous to exploit the similarities between different mixtures to reduce the number of computations necessary to cover the range of conditions of interest. Thus, if their behaviour can be generalized, fewer variations of parameters are required and the results are more concise and have greater usefulness. Accordingly, this section summarizes our knowlegde of the pertinent transport properties. In conjunction with the following section it demonstrates that, as a first approximation, the variation in mixture composition can be reflected in the analysis in terms of a single variable parameter, the inlet Prandtl number.

The Lennard-Jones (6-12) potential can be employed in the Chapman-Enskog kinetic theory to predict thermal conductivity, viscosity and Prandtl number of binary mixtures of the inert gases [14]. There has been considerable experimental study of the pure gases, particularly helium and argon, but few data on their mixtures exist to check the predictions.

With force constants, ϵ/κ and σ, as suggested by Hirschfelder, Curtiss and Bird [14] the prediction of the helium viscosity falls about eight percent below the data of Dawe and Smith [15] and Kalelkar and Kestin [16] at temperatures around 900°C. Likewise, the predicted thermal conductivity is about nine percent lower than the measurements of Saxena and Saxena [17] up to 1100°C. Similar discrepancies occur for xenon, but agreement with argon data is close. In general, agreement is good near room temperature for these gases.

Thornton [18] measured viscosity of the helium/xenon system at 20°C. His data agree with the predictions to within a few percent. On the other hand, the thermal conductivities obtained by Mason and von Ubish [19] at 520°C show an increasing divergence from the predicted curve as the fraction of helium is increased. Using force constants suggested by DiPippo and Kestin [20] for the helium component, instead of those of Hirschfelder, Curtiss and Bird, leads to essential agreement with the recommended value from the Thermophysical Properties Research Center [21].

Thermal conductivity and viscosity are presented against logarithmic coordinates in Figure 1 for helium, xenon, argon and some of their binary mixtures. These values are based on the Lennard-Jones (6-12) potential with the force constants σ = 2.158, 3.292 and 4.055 A, ϵ/κ = 86.20, 152.75 and 229 $^{\circ}$K for helium, argon and xenon, respectively. The xenon values are from Hirschfelder, Curtiss and Bird and the others from DiPippo and Kestin.

Viscosities of the noble gases and their mixtures differ only slightly with molecular weight (composition). The variation with temperature is approximately the same for all. Using an idealized temperature dependence,

$$(\mu/\mu_{ref}) = (T/T_{ref})^{a} \tag{4a}$$

one finds the exponent "a" ranging from 0.7 to 0.8. On the other hand, the values of the thermal conductivity vary over an order of magnitude from xenon to helium. Again the temperature dependence is about the same for each and can be idealized as

$$(k/k_{ref}) = (T/T_{ref})^{b} \tag{4b}$$

For the mixtures the exponent "b" is typically slightly less than "a" and ranges from about 0.7 to 0.75. As a first approximation, "a" and "b" could be taken as equal and the same value could be used for each of the mixtures. The specific heat is independent of temperature but varies with composition.

Perhaps the main surprise is the Prandtl number variation of the mixtures. Argon/helium and xenon/helium are shown in Figure 2; the other mixtures yield curves of the same shape. The temperature dependence is almost negligible since the power law exponents for k and μ differ so little. The Prandtl number of the pure gases is 2/3. However, each binary system shows a minimum at intermediate concentrations (molecular weight); for xenon/helium it is $Pr \approx 0.22$ at room temperature and is particularly broad. Other Prandtl number minima are : krypton/helium, 0.32; argon/helium, 0.42; krypton/neon, 0.53; xenon/argon, 0.57. Thus, Prandtl numbers in the range 0.5 to 2/3 can be obtained with several choices of binary mixture and concentration.

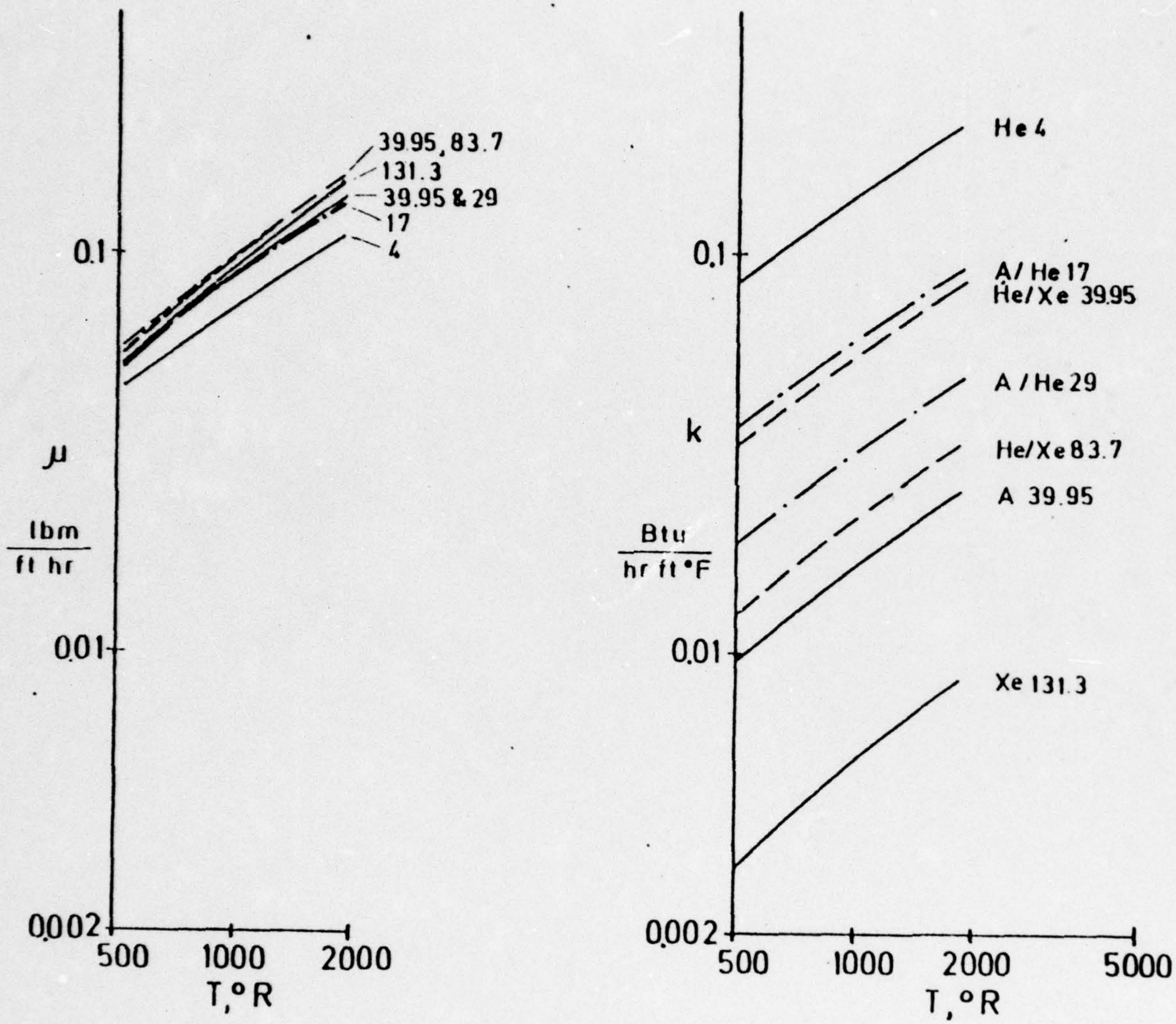

Figure 1. Transport properties of noble gas mixtures, Number indicates molecular weight of mixtures.

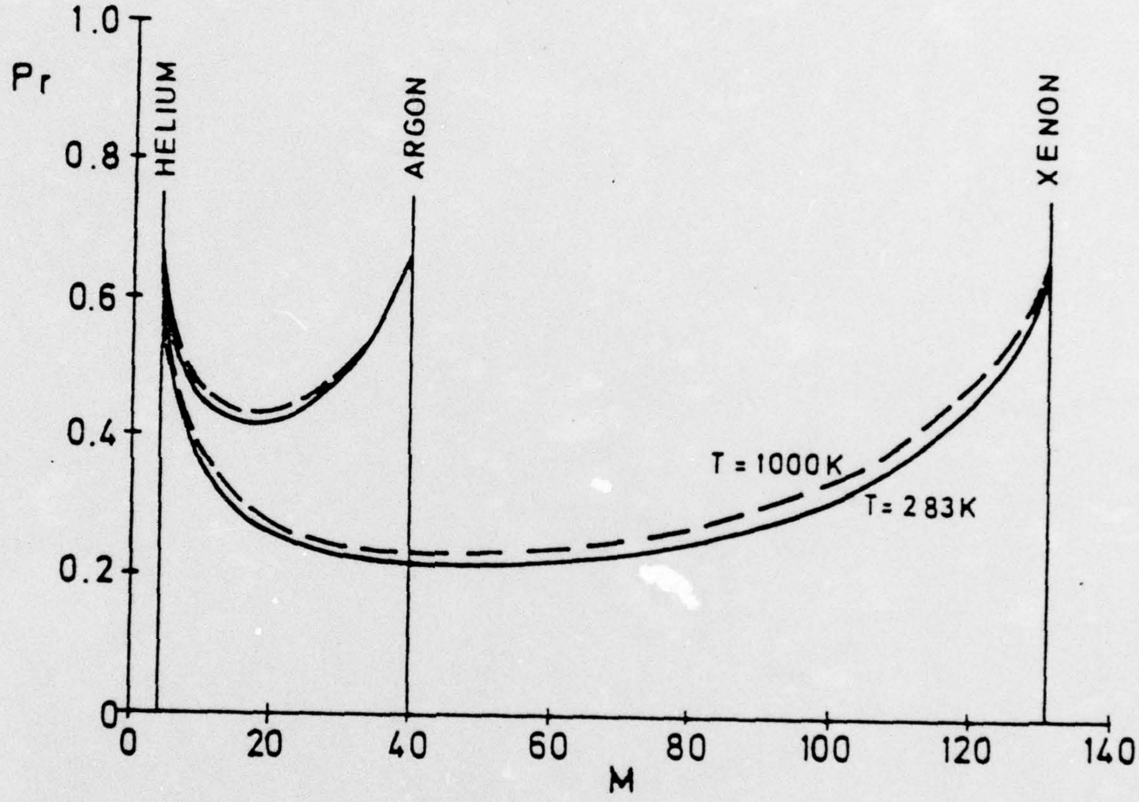

Figure 2. Prandtl number variation with concentration (molecular weight).

4. ANALYSIS

The details of the numerical analysis are straight forward and effectively the same as other methods for solution of coupled parabolic partial differential equations (e.g., reference [22]) so only the essentials will be outlined here. The number of parameters which must be varied to describe the range of conditions possible is determined by examination of the non-dimensional equations governing the problem.

Under the steady, internal boundary layer approximations - plus the assumptions that (a) mixture concentration remains constant, (b) Mach number << 1, (c) RePr $\gtrsim$ 100, and (d) natural convection is negligible - the governing equations can be written :

Continuity:

$$\frac{\partial \hat{\rho} \hat{u}}{\partial x^{+}} + \frac{\partial \hat{\rho} v^{+}}{\partial \bar{y}} = 0 \tag{5a}$$

x-momentum :

$$\hat{\rho} \hat{u} \frac{\partial \hat{u}}{\partial x^{+}} + \hat{\rho} v^{+} \frac{\partial \hat{u}}{\partial \bar{y}} = - \frac{1}{2} \frac{d \bar{p}}{d x^{+}} + \frac{1}{4} \frac{\partial}{\partial \bar{y}} \left(\hat{\mu} \frac{\partial \hat{u}}{\partial \bar{y}} \right) \tag{5b}$$

Energy :

$$\hat{\rho} \hat{u} \frac{\partial \bar{H}}{\partial x^{+}} + \hat{\rho} v^{+} \frac{\partial \bar{H}}{\partial \bar{y}} = \frac{1}{4 Pr_{o}} \frac{\partial}{\partial \bar{y}} \left(\hat{k} \frac{\partial \hat{T}}{\partial \bar{y}} \right) \tag{5c}$$

Integral continuity :

$$\int_{0}^{\bar{y}=1/2} \hat{\rho} \hat{u} \, d \bar{y} = \frac{1}{2} \tag{5d}$$

A circumflex (^) represents non-dimensionalization with respect to the value of the quantity at the entrance.

The gas properties may be idealized as :

$$\hat{\rho} = \frac{\bar{p}}{\bar{p}_{o} \hat{T}} ; \quad \hat{\mu} = \hat{T}^{a} ; \quad \hat{k} = \hat{T}^{b} ; \quad \hat{c}_{p} = \hat{T}^{d} \tag{6}$$

Initial conditions are : $\hat{T}(0,\bar{y}) = 1$, $\bar{p}_{o}$ specified and $\hat{u}(0,\bar{y}) = 1$, i.e.,

uniform entry. Boundary conditions are (1) the nonslip condition for velocities, (2) constant wall heat flux,

$$- \left(\hat{k} \cdot \frac{\partial \hat{T}}{\partial \bar{y}} \right) = Q^{+} \qquad (7)$$

and (3) symmetry of the flow and boundary conditions with respect to the centre plane.

Examination of equations (5), (6) and (7) shows the free parameters of the mathematical statement are Pr_o, Q^+, $\bar{p}_o$ and the property exponents a, b and d. For the present paper a and b are taken as 0.75, d as zero and $\bar{p}_o$ is set sufficiently high that the Mach number is small in the range of interest. The parameters Pr_o (corresponding to the mixture molecular weight) and Q^+, the heating rate, remain variable.

The problem is solved numerically with program BAND, developed by Greif and McEligot [23] for flows between parallel plates with thermal radiative interaction using a band absorptance model. For the present calculations the capability to handle thermal radiation was suppressed, but property variation was included by choosing non-zero values of the exponents a and b. The numerical program is a finite control volume analysis using implicit algebraic equations to represent the governing equations; these equations are iterated at each axial step to treat their coupling and the nonlinear terms.

Mesh spacing increases in both the transverse and axial directions. For the results reported here, 81 transverse nodes were employed with the first usually at $(y/D_h) = 0.001$, and longitudinally there were 20 steps per decade normally starting at $x_o = 10^{-5}$. As noted by Worsoe-Schmidt and Leppert [13] the boundary layer approximations are not appropriate for $x^* < 10^{-3}$ so no results are reported for the initial two axial decades. Prior tests have shown convergence within 2 percent for Nu and within about 1 percent for f_{ap} with this grid.

5. RESULTS

Predictions have been obtained for the ranges $0.2 \leq Pr \leq 2/3$, corresponding to the Prandtl number variation from mixtures to pure gases, and $-2 \leq Q^+ \leq 100$. For $Q^+ \leq 10$, $\bar{p}_o$ was taken as 10^3 giving an inlet Mach number of 0.035 while at higher Q^+, $\bar{p}_o = 10^4$ for $M_o = 0.011$. Pertinent wall parameters are listed in Appendix A for all conditions studied in this investigation.

With heating at a constant wall heat flux, the local bulk temperature increases continuously; with constant specific heat this increase is linear. The viscosity increases with temperature, so the local bulk Reynolds number (GD_h/μ_{bx}) decreases in the axial direction and the flow would be expected to remain laminar. Density is inversely proportional to temperature so the flow accelerates as it is heated, also normally a stabilizing influence. This continuous acceleration prohibits the occurance of invariant velocity and temperature profiles. The wall temperature is larger than the bulk temperature in order to transfer energy to the gas so, at a given cross section, the viscosity and thermal conductivity will be higher near the wall and the density will be lower. Consequently, parameters defined in terms of wall properties will have different values than those using bulk properties in their definition. While the increase in viscosity is expected to increase the wall shear stress and decrease the velocity near the wall, thus increasing thermal resistance, the increase in thermal conductivity is a factor tending to reduce thermal resistance. Likewise, the expansion due to reduced density counteracts the decrease due to viscosity to some extent. Near the entrance, the increasedviscosity and decreased density at the wall augment the non-slip condition causing transverse flow away from the wall; this flow also carries thermal energy. Further downstream the transverse flow decreases. (These various effects are reversed with cooling). While the individual effects of these phenomena can be forecast in some cases, their combined effect is not obvious and may vary with geometry. Since density, viscosity and thermal conductivity variations are all of the same order of magnitude, none dominates in such a way that a single-parameter, closed-form analysis would appear feasible.

For the present study the presentation of results emphasizes mean parameters which are useful to design engineers; however, local Nusselt numbers and friction factors are included in the Tables for those interested. With pro-

perty variation, parameters can take a number of values depending on how the temperatures which are used to evaluate the pertinent properties are defined. To avoid later confusion in the use of these predictions it is necessary to be explicit in the definitions.

Local bulk temperature, T_{bx}, is the temperature corresponding to the total enthalpy flow at a cross section, i.e., the socalled mixing cup temperature. Average bulk temperature, T_{ba}, is the arithmetic average of the local value at length L and the inlet value

$$T_{ba} = (T_{bo} + T_{bL})/2$$

While an integral average is normally used for the average wall temperature in analyses it is not of use to the designer who lacks the detailed knowledge of $T_w(x)$; accordingly, we define T_{wa} as an arithmetic average

$$T_{wa} = (T_{wo} + T_{wL})/2$$

which becomes, for constant wall heat flux,

$$T_{wa} = (T_{bo} + T_{wL})/2$$

(Thus, T_{wa} is lower than $\int T_w(x)\, dx/L$). Then, in agreement with normal practise, an average film temperature is chosen as

$$T_{fa} = (T_{wa} + T_{ba})/2$$

Comparable subscripting is used for indentifying the temperature at which properties are evaluated, e.g., $\mu_{ba} = \mu(T_{ba})$, and similarly for non-dimensional parameters, $Re_{ba} = GD_h/\mu_{ba}$. Average pressure is also taken at the arithmetic average of inlet and exit, L. Other quantities will be defined later as used.

Predictions for constant fluid properties

For small heating rates or low temperature differences the constant properties idealization is often adequate for practical applications. For example, one sees in Figure 1 that a 50°C difference in temperature causes a change in thermal conductivity of about 17 % at room temperature and 4 % at 1000°K. In Figure 3 are plotted the mean Nusselt numbers versus non-dimensional length, $L^* = 4L/(D_h Re Pr)$, as obtained by setting the property variation exponents, a

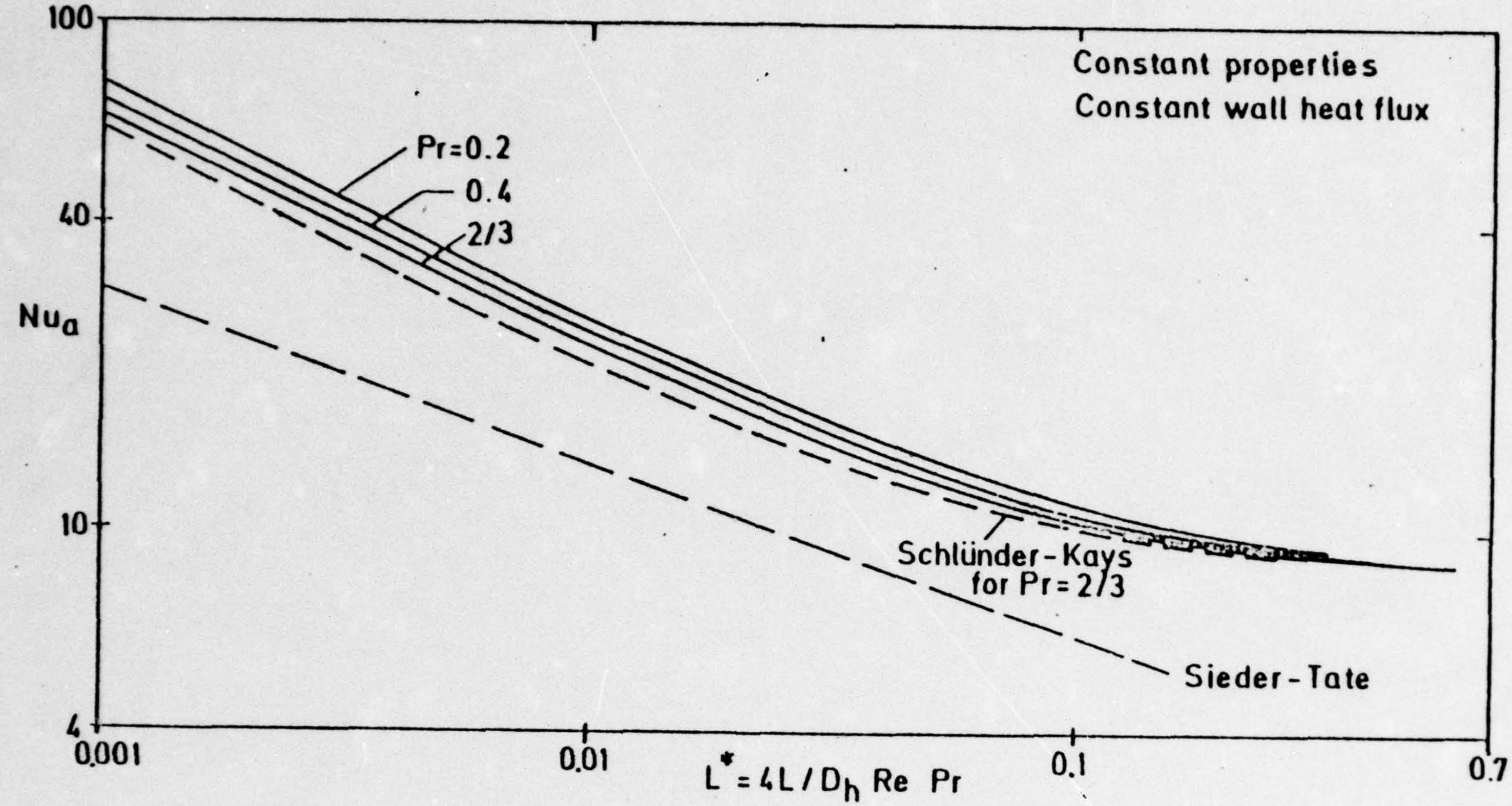

Figure 3. Mean heat transfer predictions under constant properties idealization.

and b, at zero and holding $\hat{\rho} = 1$. The mean Nusselt number is defined in terms of the integral average heat transfer coefficient as

$$Nu_a = \frac{h_a \cdot D_h}{k} = \frac{D_h}{kL} \int_0^L h(x)\,dx$$

From Figure 3 one sees that in the entry $Nu_a(L^*)$ increases as the Prandtl number is reduced by employing different inert gas mixtures. This increase is approximately 17% as Pr varies from 2/3 to 0.2. Since, for constant properties, the development of the shear boundary layer is a function of $x^+ = 4x/(D_h Re)$ and is independent of Prandtl number (i.e., it is a solution of equations (5a, b and d), the velocity profile is more fully developed for $Pr = 2/3$ than for $Pr = 0.2$ at any specified value of L^*. Consequently, the increase in Nu_a coincides with a higher average velocity gradient, $(\partial u/\partial y)_a$, between 0 and L^*; with increased velocities near the wall an increase in heat transfer parameters is reasonable.

Also plotted on Figure 3 is the Sieder-Tate correlation (1) which has been employed in practise for heat transfer calculations in comparable situations. In addition to differing by as much as a factor of two in the range of interest, this calculation fails to show the proper trend with L^* except approximately in the limited range $0.01 < L^* < 0.1$. At $L^* \approx 0.001$ the mean Nusselt number varies as $(L^*)^{-0.47}$ rather than $(L^*)^{-1/3}$ as in the Sieder-Tate correlation. Failure of this correlation to account for Prandtl number dependence has been mentioned earlier.

Based on an integral/superposition method Kays [12] suggests that the local Nusselt number for the simultaneous growth of laminar external boundary layers can be predicted by

$$Nu_x = 0.453\, Pr^{1/3}\, Re_x^{1/2} \tag{8}$$

for the thermal boundary condition of a constant wall heat flux. For the immediate entry where $T_{bx} \approx T_o$ and $V_{bx} \approx V_o$, this relation can be transformed to a mean Nusselt number

$$Nu_{m,e} = 0.906\, Pr^{1/3}\, Re_{D_h}^{1/2} D_h^{1/2} / L^{1/2} \tag{9}$$

In this case, equation (3), the form suggested by Schlünder [9], would become

$$Nu_a = \left[8.235^2 + 1.812^2/(Pr^{1/3}L^*)\right]^{1/2} \qquad (10)$$

This equation is shown on Figure 3 for a pure gas, $Pr = 2/3$, and can be seen to agree with the numerical prediction within about ten percent. For the mixtures agreement is as good or better; the comparisons are shown individually later.

It should be reemphasized that while the increase in $Nu(L^*)$ is of the order of 15 percent, when replacing a pure gas by a xenon-helium mixture, the gain in heat transfer coefficient is much greater. For example, taking equation (9) as an approximation for short fins in conjunction with Figures 1 and 2, one can see that for a given geometry and Reynolds number the effect of replacing pure argon by a helium/xenon mixture is to increase the heat transfer coefficient about 2.4 times.

Predictions of heat transfer with property variation

When fluid properties vary significantly due to high heating rates and related large temperature variations in the flow field, the numerical values of non-dimensional parameters such as Nu and Re depend on the temperature at which their properties are evaluated. Two methods of accounting for the property variation are common in practise : the film temperature approach and the property-ratio approach [12] . In the film temperature approach it is assumed that using properties evaluated at T_f will allow direct use of predictions obtained under the constant property idealization. In the property ratio approach the bulk temperature is used for the properties and the effect of heating is represented as

$$Nu / Nu_{cp} = (T_w/T_b)^p \qquad (11)$$

for gases. The effectiveness of these two methods for heat transfer predictions is examined in the present section; wall friction predictions are considered in the following section.

Figure 4 demonstrates the apparent effect of heating rate on the mean Nusselt number when the properties are taken at T_{ba}, i.e., the property ratio approach. Thus, L^*_{ba} is defined as $4L/(D_h Re_{ba} Pr) = 4L\, k_{ba}/(c_p G D_h^2)$. The effect of heating the gas in a slight increase in Nu_{ba} compared to the prediction of Nu for constant properties ($Q^+ \to 0$) at the same value of L^*_{ba}. For a

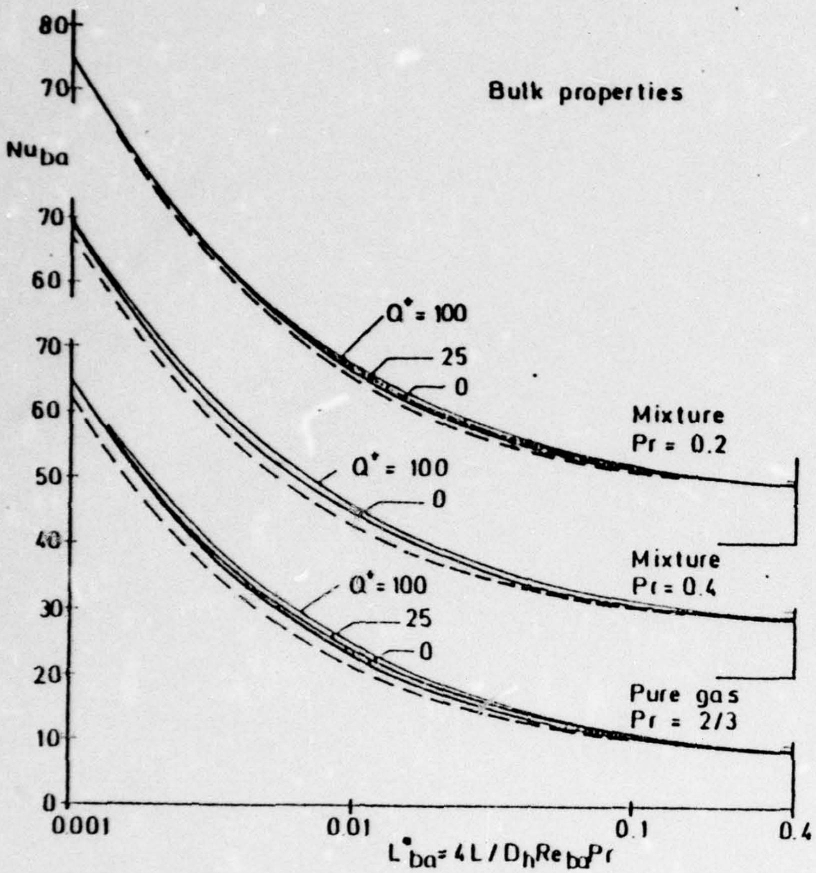

Figure 4. Mean heat transfer predictions in terms of bulk properties. Dashed line represents equation (10).

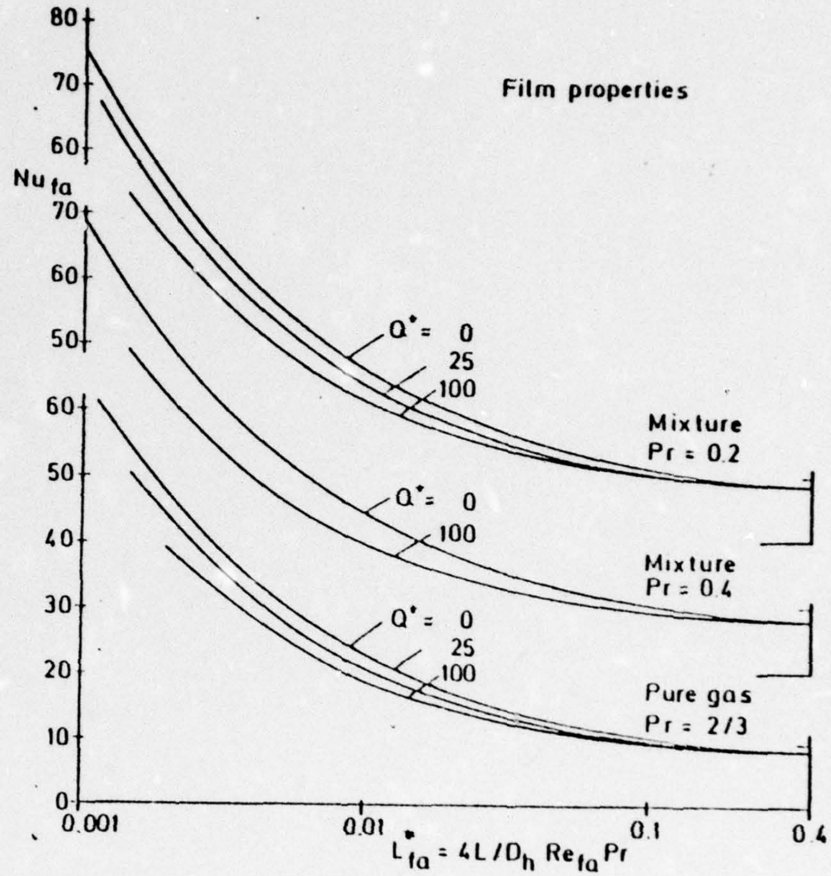

Figure 5. Mean heat transfer predictions in terms of film properties.

given value of Q^+, Nu_{ba} is increased more for the pure gases than for the mixtures, but this result is partially a consequence of the lower wall-to-bulk temperature reached by the gas with the lower Prandtl number. However, for $Q^+ = 100$, which leads to $(T_{wa}/T_{ba})_{max}$ around 2.5 to 2.7, the increase is only of the order of five percent. Thus, the exponent p in equation (11) would be about 0.05, which can probably be considered negligible for most practical cases. On the other hand, for $Q^+ = 100$ and $Pr = 2/3$ the local Nusselt number Nu_{bx} reaches a peak increase over the constant property prediction of about twenty-five percent at a location where $T_{wx}/T_{bx} \approx 3$ so the mean Nusselt number is affected even less than the local value.

To examine whether the film temperature approach is an improvement, the results are plotted in Figure 5 with properties evaluated at the average film temperature, $Nu_{fa} = h_a D_h / k_{fa}$ and $L^*_{fa} = 4Lk_{fa}/c_p G D_h^{\,2}$. With this choice the mean Nusselt numbers decrease as the heating rate is raised. This effect is of approximately the same magnitude for the pure gases as for the mixtures with their lower Prandtl numbers. The most significant observation is that the reduction is about three times as great as the change when using bulk properties (Figure 4) so there is no advantage in accuracy with the film temperature approach.

When heating the gas T_w and T_b both increase, T_w more rapidly in the entrance region and then both at approximately the same rate at larger distances. Consequently, T_w/T_b first increases and then approaches unity axially. Likewise, $Nu_{ba}(L^*)$ is first greater than $Nu_{cp}(L^*)$ and then approaches $Nu_{cp}(L^*)$ downstream. In this situation correlations of the form of equation (11) make sense. In contrast, when cooling the gas - as on the opposite side of a regenerative heat exchanger - both temperatures decrease continuously such that, in the limit, T_w/T_b approaches zero or T_b/T_w approaches infinity. The relative property variation across the flow becomes greater downstream instead of less as in the heating situation. This limit is not likely to be of concern in a gas turbine cycle since the lowest temperature is set by the inlet temperature of the side to be heated, but might be a difficulty in cryogenic applications. In the cooling range covered in the scope of the present paper, $Nu_{ba}(L^*_{ba})$ remained sufficiently close to $Nu_{cp}(L^*)$ to neglect the difference.

If one calls equation (10) the Schlünder-Kays relation and plots it as

a dashed line on each of the subfigures of Figure 4, it may be seen that agreement with the constant property result is good for each case but successively better as Pr is reduced. Since $Nu_{ba}(L^*_{ba})$ is predicted so closely by $Nu_{cp}(L^*)$ it is worthwhile to improve the equation so it may be used by the designer over the range of interest. By adjusting the Prandtl number dependence of $Nu_{m,e}$ for better prediction at $L^* = 0.001$, one may obtain

$$Nu_a = \left[8.235^2 + 1.931^2/(Pr^{0.254}L^*) \right]^{1/2} \quad (12)$$

This equation still is of the order of five percent lower than the numerical prediction near $L^* = 0.01$. For moderate heating rates it would be within about ten percent of the numerical results and would be low; in heat exchanger design this would lead to units slightly longer than necessary. Alternatively, the constants in equation (12) could be optimized for another range at the expense of the accuracy of predictions in the immediate entry.

Prediction of wall friction with property variation

While most analyses presently available for developing flows present friction results in terms of the wall shear stress evaluated from the velocity gradient at the wall (f_s), this approach is not of use to the designer when the velocity profile is changing substantially, as in the entry or when a gas is heated. To predict the required pressure drop with a one-dimensional design procedure, one uses the "apparent" friction factor, f_{ap}, based on the wall shear determined by treating the momentum change as one-dimensional. The same treatment is often employed in experiments where size prohibits velocity profile measurements. Both methods of presentation can be chosen with numerical results; consequently, Bankston and McEligot [22] were able to demonstrate (a) the numerical values of f_s and f_{ap} can differ substantially and (b) discrepancies earlier thought to exist between experiments and analyses were primarily due to the differences in the definition used for the friction factors.

As with the heat transfer results we concentrate in presenting a mean apparent friction factor,

$$f_a = -\frac{D_h}{4L} \frac{\rho}{G^2/2g_c} \underset{0\;\;L}{\Delta} \left\{ p + \frac{G^2}{\rho_b g_c} \right\} \quad (13)$$

(The local apparent friction factor, f_x, appearing in the Tables is defined in the analogous derivative form with d/dx replacing $(\frac{1}{L}) \underset{0\;\;L}{\Delta}$). When ρ_b

is constant, the second term in brackets does not change and the definition reduces to that of Shah and London [7] . With constant fluid properties one solves equations (5a), (5b) and (5d) only, so the result is independent of Prandtl number and can be written as a single function $f_a(L^+)$ which approaches $f_a \cdot Re/24$ as L^+ becomes large. This function may be found tabulated in Appendix A or can be derived from earlier local results [10, 24] . For a continuous approximation, the approach of Schlünder can be used as in equation (13) to give

$$f_a \cdot Re/24 = \sqrt{1 + 0.0788/L^+} \tag{14}$$

which represents the numerical results well in the immediate entry but is 4 to 5 percent high in the range, $0.05 < L^+ < 0.2$.

With varying transport properties, the energy equation (5c) is coupled to equations (5a, b and d) via the temperature-dependent viscosity and density, so the wall friction also becomes a function of the Prandtl number and the heating rate. Again the question arises as to the better method of accounting for the fluid property variations. Predictions of friction are not as well behaved as heat transfer parameters. In contrast to the heat transfer results, direct use of the average bulk properties in $f_a \cdot Re$ and L^+ does not collapse the results nicely around the prediction based on constant properties; the main effect is to spread the curves towards larger L^+_{ba} as Q^+ increases.

The effect of heating rate on apparent wall friction is presented in Figure 6 partially in terms of average bulk properties. That is, ρ_{ba} is used for the coefficient in equation (13) and Re_{ba} is defined as before but the non-dimensional length is based on inlet properties, i.e., L^+_o. With this representation heating increases $f_{ba} \cdot Re_{ba}$ considerably more than Nu_{ba} is raised at the same level of Q^+. At lengths greater than $L^+ = 0.1$ the curves with heating approach the constant properties curve only slowly, although T_{wa}/T_{ba} is close to unity, as the heated entry continues to affect the integrated results far downstream. Close inspection of the trends for the highest heating rates shows that as Pr increases a convergence - from heated entry behavior towards agreement with constant property behavior - is moved further downstream. This effect corresponds to the difference in growth of the thermal boundary layer and shear boundary layer as the Prandtl number changes : $Nu(L^*)$ shows only a moderate effect of Pr, so for the same heating rate the

value of T_w/T_b is almost the same at equal value of L^* rather than L^+, thus T_w/T_b approaches unity for $Pr = 0.2$ at earlier values of L^+ than for $Pr = 2/3$ and the variation of properties across the channel is less for $Pr = 0.2$ at the same L^+. While the friction predictions for heating approach the adiabatic prediction as L_{ba}^+ increases, those for cooling diverge; this result also corresponds to the trend of property variation since the ratio T_{ba}/T_{wa} increases downstream for cooling as described earlier in the section on heat transfer.

As with the heat transfer results, the apparent effect of property variation on wall friction is sensitive to the choice of reference temperature. With average film temperature for the reference, the shape of the resulting curves differs from the shape with bulk temperature as reference. In Figure 7 the product $f_{fa} \cdot Re_{fa}/24$ is plotted against L_o^+; ρ_{fa} is used in the coefficient in equation (13) and Re_{fa} is based on μ_{fa}. There is no advantage in comparison on the basis of L_{fa}^+ since results are shifted then further to the right (with heating) so that for $L^+ \gtrsim 0.01$ the difference from the adiabatic prediction is increased. For heating: the friction parameters are reduced for short lengths; then the predictions coverge with and cross the constant properties curve and remain slightly greater at larger distances. In comparison to the bulk property predictions, the effects for short and long ducts are approximately the same magnitude with strong heating, but for intermediate lengths and for $Q^+ \gtrsim 10$ a display in terms of film properties shows significantly less variation. In the range $-2 < Q^+ < 2$ there is no significant effect of heating until L_o^+ approaches 0.1 with film properties and then the effect is only of the order of five to ten percent. As is the case for bulk properties, the convergence towards the adiabatic prediction is at successively greater distances (L_o^+) as the Prandtl number increases, but for the same condition it is several times earlier with film properties. With cooling : the direction of the trends are reversed but for $Q^+ > -2$ they are essentially again negligible for entry problems.

It is not clear from Figure 6 and 7 which approach is better : property ratio or film temperature. The property ratio approach would be represented as

$$(f_{ba} \cdot Re(L_o^+)) / (f_a \cdot Re(L_o^+))_{cp} = (T_{wa}/T_{ba})^q \qquad (15)$$

so this quotient is plotted versus temperature ratio in Figure 8 to examine the suitability of a single exponent. A complicated pattern appears. In contrast to the expectation of Kays and London [25], the general trend is a substantial

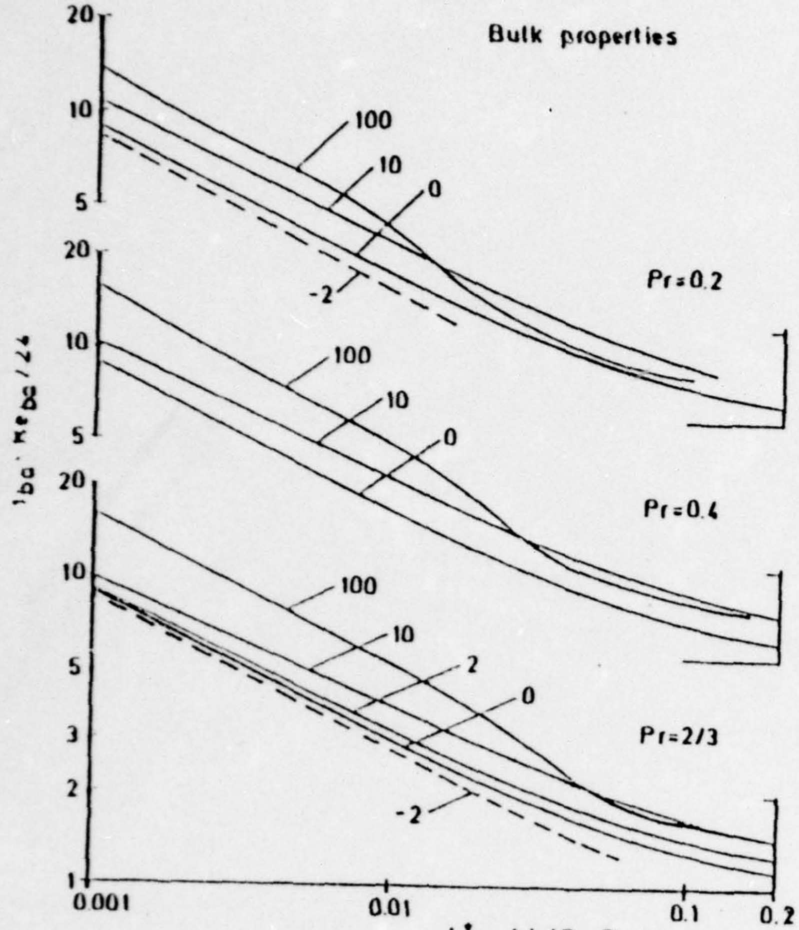

Figure 6. Mean wall friction prediction in terms of bulk properties.

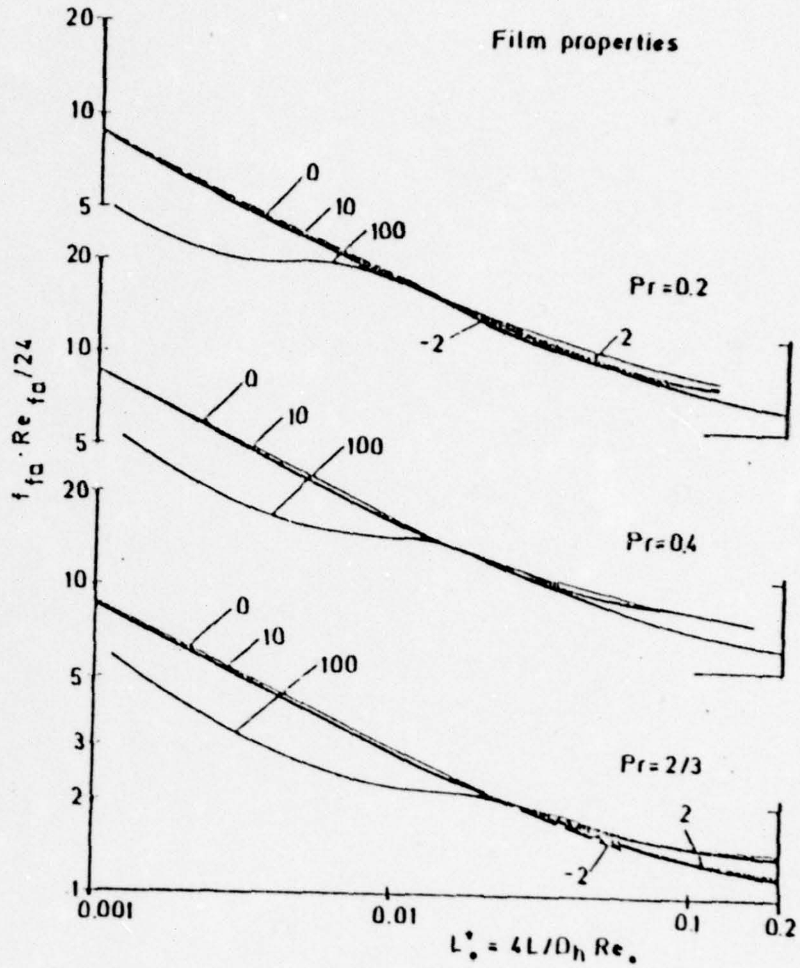

Figure 7. Mean wall friction predictions in terms of film properties.

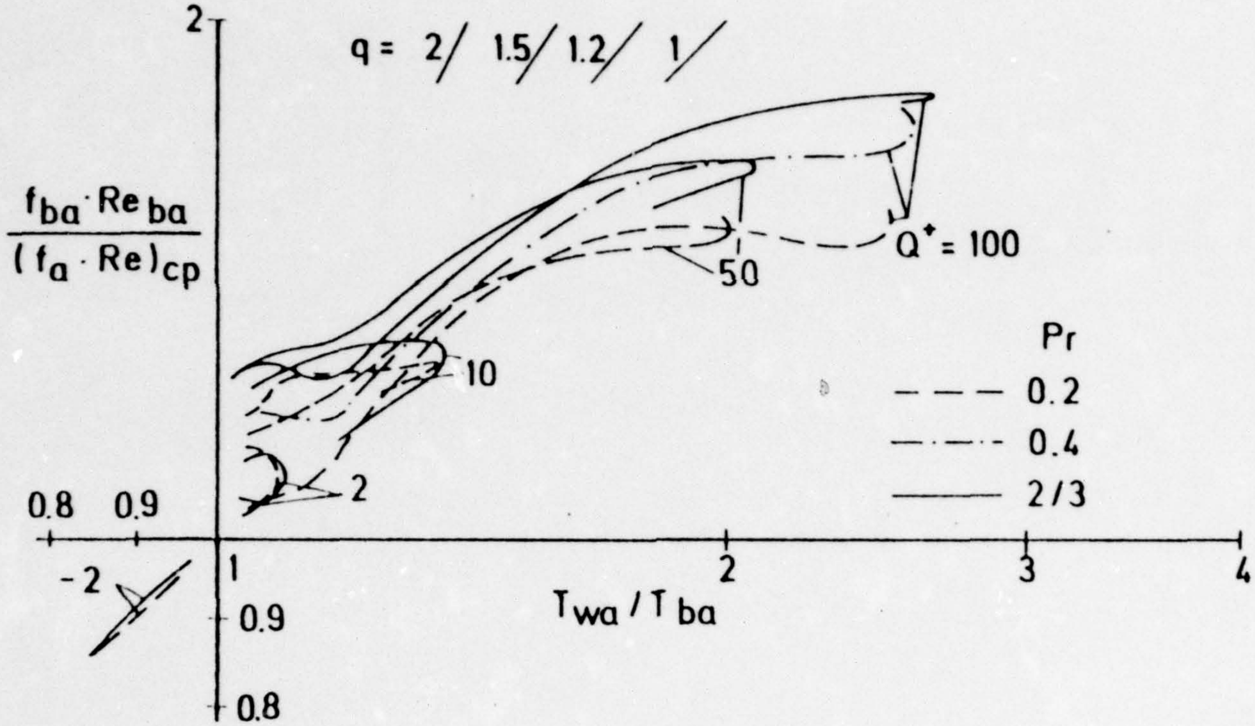

Figure 8. Examination of property ratio method for mean wall friction.

increase with temperature ratio. There are slight differences with Prandtl number but the trends are mostly the same. An exponent q of the order of unity would overpredict the friction factor at the higher temperature ratios and underpredict it at lower values. For cooling, $q = 1$ is valid within a few percent. For moderate heating, the necessary value of q (i.e., the slope of a line from the origin on this logarithmic plot) varies with length L_o^+: it is approximately constant as the temperature ratio increases with length then increases gradually as the ratio drops for successively longer ducts. The latter effect is a consequence of the slow covergence of $f_{ba} \cdot Re_{ba}$ to the adiabatic curve for long ducts as discussed earlier. It is seen that a function $q\ (L_o^+, Q^+, Pr)$ would be necessary to describe the detailed behavior. For $Q^+ = 2$ and $L_o^+ < 0.6$, an exponent $q = 1.5$ would reduce the difference from the constant properties curve from 13 percent to a 7 percent discrepancy. With $Q^+ = 10$, $q = 1.2$ is a better approximation, but the discrepancy would still reach twenty percent. These comments and comparison of Figure 6 and 8 suggest that the two methods have approximately the same overall accuracy for $Q^+ \precsim 2$ with a slight advantage to the film properties approach for short ducts. For moderate heating - to $Q^+ = 10$ - the film property method is clearly superior, while at higher heating rates both methods show regions where the simple correlations would mislead the designer substantially.

It is perhaps inconvenient for the designer to have one method perform better for heat transfer while the other is preferable for wall friction, but the difficulty should be negligible <u>provided</u> the present definitions of the parameters are used. Once the heat transfer problem is solved for the wall temperature using average bulk properties, the average film temperature can be calculated from the results and can then be employed to predict the wall friction behavior.

Analytical correlations such as equations (12) and (14) are useful for parameter studies of systems and for initial sizing of components when hundreds to thousands of individual configurations may be calculated. When greater accuracy is needed in final design decisions - or if variable wall heat flux should be treated - the numerical analysis can be employed directly. With the direct application of the program, the question of definitions of the non-dimensional parameters is avoided; the engineer can choose definitions to suit his own convenience, including direct presentation in temperatures, pressure and lengths in units of his choice.

6. CONCLUSIONS

For heat transfer to mixtures of inert gases in short ducts formed of parallel plates, the following conclusions concerning the behavior of the mean parameters are warranted. In terms of appropriate non-dimensional variables and parameters, the effects of varying mixture concentration can be represented by variation of the inlet Prandtl number. These conclusions are based on the specific definition of parameters chosen in the present work; with strong heating rates the use of alternate definitions in the correlations can cause substantially different predictions of the heat transfer coefficient and friction factor and, consequently, of the wall temperature and pressure drop.

a) Under the constant property idealization, heat transfer and apparent wall friction parameters can be approximated by

$$Nu_a = \left[8.235^2 + 1.931^2/(Pr^{0.254}L^*)\right]^{1/2}$$

and

$$(f_a \cdot Re/24) = \left[1 + 0.0788/L^+\right]^{1/2}$$

to within ten percent for L^* and L^+, respectively, greater than 0.001.

b) For heat transfer in the range $-2 < Q^+ < .100$ the bulk properties/property ratio method of accounting for the effects of gas property variation - with exponent $p \gtrsim 0.005$ - provides better predictions than the film temperature method.

c) For wall friction in the range $-2 < Q^+ < 10$ the film temperature method is more accurate overall than the property ratio approach.

ACKNOWLEDGEMENTS

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APPENDIX A

TABULATED RESULTS

This appendix presents reproductions of the summary tables of the computed results that were provided as output from the UNIVAC 1108 computer at the Rechenzentrum, Universität Karlsruhe. All cases for which predictions were calculated are included in these tables. Space limitations prohibit listing all the predicted parameters of interest; however, the set shown should provide the basic information from which others can be calculated via their definitions and the idealized property relationships. For example,

$$L^*_{ba} = \frac{4L}{D_h Re_{ba} Pr} = \frac{4L}{D_h Re_o Pr} \; \frac{Re_o}{Re_{ba}} = L^*_o \left(\frac{T_{ba}}{T_o}\right)^a = \frac{4x}{D_h Pe_o} \left(\frac{T_{ba}}{T_o}\right)^a$$

The cases calculated are:

Pr	Q^+
0.7 (air)	50, 0†
0.666 ...	100, 50, 25, 10, 2, 0, -2
0.4	100, 10, 0†
0.2	100, 50*, 25*, 10, 2, 0, -0.2, -2

†The case of $Q^+ = 0$ represents heating rates sufficiently small that the properties can be considered constant. In order to calculate these cases non-zero heat flux was chosen and the property exponents were chosen for constant properties; these are identified in the following tables by the head: VIS = .000, CON = .000, CP = .000.

*Inlet pressure relatively low, leading to excessive Mach number at last few stations.

Of necessity some of the table headings are brief so the following definitions and/or comments are appropriate :

Program Symbol	Usual Nomenclature	Definition	Comment
PR, 0	Pr_o	$(c_p \mu / k)_o$	Inlet Prandtl number
QPP·DH/K0·T0	Q^+	$q'' D_h / k_o T_o$	
GAMMA		c_p / c_v	Specific heat ratio
VIS	a		viscosity exponent in equation (6)
CON	b		thermal conductivity exponent in equation (6)
CP	d		specific heat exponent in equation (6)
4X/DPE0	x_o^*	$4x/(D_h Re_o Pr)$	
TB/TI	T_{bx}/T_o		local bulk temperature
TW/TB	T_{wx}/T_{bx}		local temperature ratio
NUBX	Nu_{bx}	hD_h/k_{bx}	local bulk Nusselt number
FRB/24	$f_{bx} \cdot Re_{bx}/24$		local apparent friction product, based on bulk properties, see pg.14
WA/BA	T_{wa}/T_{ba}		average temperature ratio, see pg. 10
NUBA	Nu_{ba}	$h_a D_h / k_{ba}$	average bulk Nusselt number, see pg. 11
FRBA/24	$f_{ba} \cdot Re_{ba}/24$		mean apparent friction product, based on bulk properties, eq.(13) and pg. 15
P0-PI	$\bar{p}_o - \bar{p}_x$	$2g_c \rho_o (p_o - p)/G^2$	pressure drop, note pg.9

K
$$= \hat{\rho}_{ba}\left(\bar{p}_o - \bar{p}_L\right) - 2\hat{\rho}_{ba}\left[\frac{1}{\hat{\rho}_{bL}} - 1\right] - \frac{24 x^*_{ba}}{2+a}\ \frac{\hat{\rho}_{ba}}{(\hat{T}_{ba})^a}\left[\frac{\hat{T}_{bL}^{\,2+a} - 1}{\hat{T}_{bL} - 1}\right]$$

comparable to K(x) of Shah and London [7] - but error in output in earlier constant property results.

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,O= .700, QPP.DH/KO.TO= 50.0, GAMMA=1.400

PROPERTY EXPONENTS, VIS= .670,CON= .805,CP= .095

4X/DPED	TB/TI	TW/TB	NUBK	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.05	2.260	36.35	9.235	1.645	66.132	15.361	3.688-01
1.30-03	1.06	2.371	32.52	7.775	1.707	58.668	13.718	4.449-01
1.75-03	1.09	2.492	28.35	6.958	1.777	51.274	11.988	5.514-01
2.30-03	1.11	2.596	25.83	6.112	1.841	45.339	10.590	6.758-01
3.00-03	1.15	2.686	23.15	5.492	1.901	40.255	9.373	8.263-01
3.60-03	1.18	2.732	21.52	5.157	1.936	37.096	8.629	9.550-01
4.50-03	1.22	2.774	19.66	4.671	1.975	33.573	7.772	1.141+00
5.50-03	1.27	2.788	18.14	4.386	2.000	30.685	7.099	1.351+00
6.60-03	1.32	2.788	16.87	4.049	2.018	28.282	6.527	1.577+00
8.00-03	1.39	2.764	15.62	3.789	2.026	25.939	5.976	1.866+00
1.00-02	1.47	2.708	14.30	3.525	2.021	23.460	5.406	2.283+00
1.30-02	1.63	2.599	12.92	3.240	1.991	20.834	4.822	2.931+00
1.75-02	1.84	2.431	11.57	2.933	1.928	18.221	4.249	3.941+00
2.30-02	2.10	2.238	10.56	2.648	1.839	16.127	3.792	5.259+00
3.00-02	2.43	2.029	9.81	2.346	1.729	14.377	3.390	7.058+00
3.60-02	2.70	1.834	9.42	2.128	1.645	13.341	3.125	8.691+00
4.50-02	3.11	1.712	9.07	1.876	1.538	12.252	2.812	1.130+01
5.50-02	3.55	1.572	8.87	1.672	1.446	11.439	2.543	1.441+01
6.60-02	4.04	1.461	8.74	1.523	1.369	10.827	2.316	1.811+01
8.00-02	4.65	1.362	8.63	1.417	1.298	10.296	2.103	2.333+01
1.00-01	5.50	1.270	8.54	1.334	1.228	9.806	1.898	3.193+01
2.00-01	9.63	1.100	8.35	1.199	1.091	8.873	1.581	1.045+02
3.00-01	13.60	1.054	8.31	1.123	1.050	8.612	1.457	2.312+02
4.00-01	17.45	1.035	8.29	1.089	1.033	8.500	1.397	4.267+02
5.00-01	21.22	1.024	8.27	1.072	1.023	8.438	1.364	7.062+02

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .700, QPR.DH/K0.T0= 200.0, GAMMA=1.400

PROPERTY EXPONENTS, VIS= .000,CON= .000,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24
1.00-03			34.46	5.356		64.738	10.548
1.15-03			32.39	5.083		60.654	9.853
1.30-03			30.68	4.760		57.294	9.287
1.50-03			28.80	4.406		53.621	8.650
1.75-03			26.94	4.099		49.942	8.025
2.00-03			25.42	3.848		46.972	7.512
2.30-03			23.95	3.646		44.065	7.022
2.60-03			22.73	3.441		41.673	6.620
3.00-03			21.40	3.208		39.058	6.180
3.30-03			20.56	3.061		37.415	5.902
3.60-03			19.82	2.955		35.979	5.660
4.00-03			18.98	2.830		34.322	5.384
4.50-03			18.10	2.675		32.569	5.090
5.00-03			17.36	2.555		31.085	4.842
5.50-03			16.71	2.441		29.807	4.629
6.00-03			16.15	2.350		28.693	4.442
6.60-03			15.57	2.266		27.526	4.248
7.20-03			15.06	2.173		26.508	4.079
8.00-03			14.48	2.075		25.334	3.883
9.00-03			13.87	1.978		24.095	3.676
1.00-02			13.36	1.889		23.047	3.502
1.15-02			12.73	1.782		21.742	3.283
1.30-02			12.21	1.697		20.672	3.105
1.50-02			11.66	1.605		19.507	2.910
1.75-02			11.11	1.517		18.347	2.717
2.00-02			10.68	1.445		17.416	2.562
2.30-02			10.27	1.375		16.511	2.411
2.60-02			9.95	1.319		15.773	2.288
3.00-02			9.61	1.259		14.973	2.154
3.30-02			9.40	1.224		14.477	2.071
3.60-02			9.23	1.192		14.047	1.999
4.00-02			9.05	1.157		13.556	1.916
4.50-02			8.87	1.122		13.046	1.830
5.00-02			8.73	1.096		12.621	1.757
5.50-02			8.63	1.076		12.263	1.696
6.00-02			8.54	1.059		11.957	1.644
6.60-02			8.47	1.044		11.643	1.590
7.20-02			8.41	1.033		11.376	1.544
8.00-02			8.36	1.023		11.077	1.492
9.00-02			8.32	1.014		10.773	1.439
1.00-01			8.29	1.010		10.526	1.397
1.50-01			8.25	1.002		9.773	1.266
2.00-01			8.24	1.001		9.390	1.199
2.50-01			8.24	1.001		9.160	1.160
3.00-01			8.24	1.001		9.006	1.133
3.50-01			8.24	1.001		8.896	1.114
4.00-01			8.24	1.001		8.814	1.100
4.50-01			8.24	1.001		8.750	1.089
5.00-01			8.24	1.001		8.699	1.080
5.50-01			8.24	1.001		8.657	1.073

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR.O= .667. QPP.DH/KO.TO= 100.0. GAMMA=1.667

PROPERTY EXPONENTS. VIS= .750.CON= .750.CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.30-03	1.13	3.512	32.14	10.118	2.333	57.728	17.092	6.572-01
1.75-03	1.17	3.665	28.33	8.674	2.439	50.321	14.912	8.318-01
2.30-03	1.23	3.762	25.25	7.794	2.523	44.337	13.094	1.040+00
3.00-03	1.30	3.810	22.53	6.919	2.587	39.181	11.506	1.302+00
3.60-03	1.36	3.810	20.81	6.339	2.619	35.970	10.533	1.528+00
4.50-03	1.45	3.774	18.86	5.850	2.641	32.367	9.432	1.864+00
5.50-03	1.55	3.696	17.26	5.410	2.638	29.398	8.552	2.247+00
6.60-03	1.66	3.586	15.93	5.073	2.614	26.898	7.823	2.682+00
8.00-03	1.80	3.443	14.62	4.701	2.571	24.474	7.132	3.249+00
1.00-02	2.00	3.243	13.25	4.319	2.495	21.914	6.418	4.090+00
1.30-02	2.30	2.960	11.87	3.888	2.366	19.211	5.677	5.442+00
1.75-02	2.75	2.605	10.60	3.372	2.177	16.555	4.939	7.665+00
2.30-02	3.30	2.271	9.73	2.849	1.976	14.492	4.304	1.066+01
3.00-02	4.00	1.966	9.15	2.339	1.773	12.836	3.701	1.485+01
3.60-02	4.60	1.778	8.90	2.022	1.639	11.896	3.293	1.873+01
4.50-02	5.50	1.582	8.70	1.723	1.492	10.954	2.832	2.510+01
5.50-02	6.50	1.440	8.58	1.518	1.382	10.284	2.469	3.305+01
6.60-02	7.60	1.338	8.51	1.392	1.299	9.796	2.193	4.307+01
8.00-02	9.00	1.253	8.44	1.307	1.228	9.385	1.960	5.818+01
1.00-01	11.00	1.180	8.38	1.268	1.165	9.015	1.757	8.514+01
2.00-01	21.00	1.059	8.28	1.197	1.056	8.334	1.529	3.728+02
3.00-01	31.00	1.030	8.26	1.138	1.029	8.157	1.428	9.899+02
4.00-01	40.99	1.018	8.26	1.139	1.018	8.083	1.386	2.149+03

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR.O= .667, QPP.DH/KO.TO= 50.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.30-03	1.06	2.428	31.39	8.494	1.736	57.544	14.514	4.478-01
1.75-03	1.09	2.555	27.80	7.677	1.810	50.165	12.781	5.591-01
2.30-03	1.11	2.665	24.85	6.870	1.877	44.264	11.358	6.893-01
3.00-03	1.15	2.761	22.28	6.129	1.941	39.230	10.104	8.470-01
3.60-03	1.18	2.814	20.67	5.636	1.981	36.111	9.320	9.807-01
4.50-03	1.22	2.859	18.90	5.216	2.023	32.635	8.436	1.178+00
5.50-03	1.27	2.879	17.43	4.817	2.053	29.797	7.706	1.396+00
6.60-03	1.33	2.878	16.20	4.513	2.071	27.431	7.101	1.636+00
8.00-03	1.40	2.854	15.00	4.206	2.081	25.135	6.514	1.943+00
1.00-02	1.50	2.791	13.75	3.904	2.074	22.704	5.904	2.393+00
1.30-02	1.65	2.675	12.43	3.543	2.043	20.138	5.252	3.088+00
1.75-02	1.87	2.494	11.15	3.156	1.974	17.591	4.609	4.184+00
2.30-02	2.15	2.286	10.20	2.803	1.877	15.554	4.079	5.622+00
3.00-02	2.50	2.059	9.51	2.440	1.756	13.851	3.605	7.608+00
3.60-02	2.80	1.902	9.16	2.192	1.664	12.844	3.289	9.427+00
4.50-02	3.25	1.718	8.86	1.911	1.549	11.791	2.920	1.237+01
5.50-02	3.75	1.570	8.69	1.687	1.450	11.007	2.608	1.594+01
6.60-02	4.30	1.453	8.59	1.530	1.368	10.418	2.348	2.027+01
8.00-02	5.00	1.351	8.52	1.413	1.293	9.909	2.110	2.651+01
1.00-01	6.00	1.258	8.44	1.341	1.221	9.440	1.885	3.710+01
2.00-01	11.00	1.091	8.30	1.211	1.083	8.540	1.564	1.362+02
3.00-01	16.00	1.047	8.28	1.131	1.044	8.287	1.436	3.275+02
4.00-01	20.99	1.029	8.27	1.098	1.028	8.174	1.375	6.470+02
5.00-01	25.99	1.020	8.26	1.083	1.019	8.112	1.343	1.139+03
6.00-01	30.99	1.015	8.26	1.080	1.014	8.074	1.324	1.869+03

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR.0= .667, QPP.DH/K0.T0= 25.0, GAMMA=1.667

PROPERTY EXPONENTS. VIS= .750.CON= .750.CP= .000

4X/DPE0	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	P0-PI
1.00-03	1.03	1.686	34.88	7.883	1.347	65.189	14.181	2.823-01
1.30-03	1.03	1.758	31.15	7.218	1.385	57.678	12.618	3.356-01
1.75-03	1.04	1.840	27.58	6.450	1.429	50.279	11.164	4.135-01
2.30-03	1.06	1.921	24.61	5.832	1.473	44.381	9.909	4.988-01
3.00-03	1.08	1.997	22.08	5.188	1.517	39.350	8.833	6.034-01
3.60-03	1.09	2.051	20.46	4.848	1.548	36.251	8.138	6.868-01
4.50-03	1.11	2.108	18.72	4.463	1.584	32.806	7.391	8.108-01
5.50-03	1.14	2.154	17.29	4.094	1.614	30.008	6.777	9.442-01
6.60-03	1.16	2.186	16.14	3.875	1.638	27.680	6.264	1.089+00
8.00-03	1.20	2.210	15.02	3.628	1.660	25.437	5.770	1.272+00
1.00-02	1.25	2.224	13.84	3.358	1.680	23.080	5.241	1.530+00
1.30-02	1.32	2.212	12.61	3.074	1.691	20.608	4.694	1.920+00
1.75-02	1.44	2.160	11.42	2.786	1.684	18.154	4.142	2.515+00
2.30-02	1.58	2.074	10.50	2.530	1.657	16.191	3.696	3.271+00
3.00-02	1.75	1.960	9.78	2.285	1.611	14.537	3.307	4.275+00
3.60-02	1.90	1.867	9.38	2.119	1.568	13.537	3.059	5.178+00
4.50-02	2.12	1.740	9.03	1.929	1.503	12.461	2.776	6.619+00
5.50-02	2.37	1.624	8.81	1.756	1.439	11.634	2.538	8.335+00
6.60-02	2.65	1.523	8.68	1.616	1.380	10.993	2.334	1.037+01
8.00-02	3.00	1.426	8.59	1.496	1.319	10.424	2.136	1.321+01
1.00-01	3.50	1.328	8.50	1.407	1.255	9.885	1.935	1.782+01
2.00-01	6.00	1.130	8.33	1.237	1.112	8.799	1.586	5.566+01
3.00-01	8.50	1.071	8.29	1.144	1.064	8.463	1.444	1.218+02
4.00-01	11.00	1.045	8.28	1.102	1.042	8.306	1.374	2.251+02
5.00-01	13.50	1.032	8.27	1.080	1.030	8.217	1.335	3.747+02
6.00-01	16.00	1.024	8.26	1.066	1.022	8.160	1.311	5.804+02

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .667, QPP.DH/K0.T0= 10.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPE0	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.01	1.283	34.71	6.706	1.142	65.042	12.114	2.160-01
1.30-03	1.01	1.316	30.94	5.987	1.159	57.558	10.758	2.529-01
1.75-03	1.02	1.356	27.27	5.261	1.180	50.172	9.407	3.031-01
2.30-03	1.02	1.396	24.25	4.736	1.200	44.271	8.334	3.596-01
3.00-03	1.03	1.437	21.77	4.265	1.222	39.245	7.415	4.262-01
3.60-03	1.04	1.467	20.15	3.984	1.237	36.154	6.853	4.803-01
4.50-03	1.04	1.502	18.43	3.640	1.257	32.729	6.221	5.569-01
5.50-03	1.05	1.534	17.05	3.387	1.274	29.954	5.707	6.381-01
6.60-03	1.07	1.562	15.91	3.161	1.290	27.659	5.282	7.241-01
8.00-03	1.08	1.590	14.82	2.940	1.306	25.452	4.869	8.295-01
1.00-02	1.10	1.618	13.69	2.717	1.324	23.143	4.433	9.748-01
1.30-02	1.13	1.644	12.53	2.495	1.342	20.737	3.975	1.186+00
1.75-02	1.17	1.661	11.41	2.269	1.357	18.371	3.521	1.496+00
2.30-02	1.23	1.660	10.55	2.085	1.364	16.490	3.156	1.871+00
3.00-02	1.30	1.641	9.86	1.928	1.362	14.905	2.844	2.351+00
3.60-02	1.36	1.616	9.48	1.827	1.355	13.944	2.650	2.770+00
4.50-02	1.45	1.573	9.11	1.718	1.339	12.904	2.436	3.415+00
5.50-02	1.55	1.523	8.88	1.624	1.318	12.091	2.261	4.163+00
6.60-02	1.66	1.472	8.72	1.546	1.295	11.449	2.116	5.027+00
8.00-02	1.80	1.415	8.62	1.475	1.267	10.866	1.978	6.199+00
1.00-01	2.00	1.348	8.53	1.413	1.232	10.301	1.836	8.028+00
2.00-01	3.00	1.175	8.37	1.266	1.131	9.121	1.553	2.102+01
3.00-01	4.00	1.106	8.33	1.176	1.085	8.720	1.429	4.114+01
4.00-01	5.00	1.072	8.30	1.133	1.060	8.520	1.364	7.063+01
5.00-01	6.00	1.052	8.29	1.111	1.045	8.399	1.327	1.123+02
6.00-01	7.00	1.040	8.28	1.101	1.035	8.320	1.306	1.699+02

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR.O= .667, QPP.DH/KO.TO= 2.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.00	1.057	34.69	5.806	1.029	65.131	11.098	1.823-01
1.30-03	1.00	1.065	30.86	5.120	1.032	57.639	9.779	2.095-01
1.75-03	1.00	1.073	27.12	4.452	1.037	50.240	8.482	2.458-01
2.30-03	1.00	1.082	24.11	3.934	1.041	44.325	7.446	2.850-01
3.00-03	1.01	1.092	21.55	3.520	1.046	39.287	6.569	3.297-01
3.60-03	1.01	1.099	19.97	3.259	1.050	36.188	6.035	3.650-01
4.50-03	1.01	1.108	18.24	2.934	1.054	32.755	5.440	4.136-01
5.50-03	1.01	1.116	16.84	2.721	1.059	29.974	4.960	4.638-01
6.60-03	1.01	1.124	15.70	2.517	1.063	27.677	4.565	5.153-01
8.00-03	1.02	1.133	14.61	2.326	1.067	25.471	4.185	5.765-01
1.00-02	1.02	1.143	13.48	2.131	1.072	23.167	3.786	6.579-01
1.30-02	1.03	1.155	12.34	1.934	1.078	20.775	3.372	7.714-01
1.75-02	1.04	1.168	11.24	1.741	1.085	18.433	2.966	9.284-01
2.30-02	1.05	1.178	10.39	1.592	1.091	16.582	2.644	1.107+00
3.00-02	1.06	1.186	9.73	1.469	1.096	15.029	2.372	1.323+00
3.60-02	1.07	1.189	9.35	1.396	1.098	14.093	2.207	1.501+00
4.50-02	1.09	1.191	8.99	1.322	1.100	13.081	2.027	1.762+00
5.50-02	1.11	1.190	8.75	1.270	1.100	12.290	1.884	2.047+00
6.60-02	1.13	1.187	8.60	1.235	1.099	11.663	1.769	2.361+00
8.00-02	1.16	1.182	8.49	1.209	1.098	11.091	1.664	2.766+00
1.00-01	1.20	1.173	8.43	1.194	1.094	10.534	1.560	3.361+00
2.00-01	1.40	1.133	8.35	1.167	1.078	9.380	1.353	6.798+00
3.00-01	1.60	1.106	8.33	1.135	1.065	8.983	1.277	1.099+01
4.00-01	1.80	1.086	8.31	1.113	1.055	8.778	1.235	1.602+01
5.00-01	2.00	1.072	8.30	1.096	1.048	8.652	1.210	2.199+01
6.00-01	2.20	1.061	8.29	1.084	1.042	8.565	1.193	2.898+01

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .667, QPP.DH/K0.T0= 100.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .000,CON= .000,CP= .000

4X/DPE0	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.15-03			32.59	5.150		61.050	10.107	1.860-01
1.30-03			30.85	4.820		57.666	9.516	1.979-01
1.50-03			28.97	4.512		53.965	8.861	2.127-01
1.75-03			27.10	4.218		50.260	8.224	2.303-01
2.00-03			25.56	3.950		47.269	7.700	2.464-01
2.30-03			24.08	3.712		44.341	7.198	2.649-01
2.60-03			22.84	3.492		41.932	6.780	2.820-01
3.00-03			21.51	3.289		39.298	6.327	3.037-01
3.30-03			20.66	3.157		37.642	6.044	3.191-01
3.60-03			19.92	3.035		36.196	5.798	3.340-01
4.00-03			19.08	2.886		34.526	5.514	3.529-01
4.50-03			18.19	2.731		32.761	5.212	3.753-01
5.00-03			17.44	2.609		31.266	4.958	3.966-01
5.50-03			16.79	2.502		29.979	4.739	4.170-01
6.00-03			16.23	2.405		28.857	4.548	4.367-01
6.60-03			15.64	2.304		27.682	4.348	4.592-01
7.20-03			15.13	2.224		26.657	4.174	4.809-01
8.00-03			14.54	2.119		25.474	3.974	5.087-01
9.00-03			13.93	2.014		24.226	3.761	5.415-01
1.00-02			13.41	1.931		23.170	3.582	5.731-01
1.15-02			12.78	1.818		21.856	3.358	6.179-01
1.30-02			12.26	1.732		20.779	3.175	6.604-01
1.50-02			11.70	1.636		19.605	2.975	7.141-01
1.75-02			11.15	1.543		18.437	2.776	7.774-01
2.00-02			10.72	1.469		17.499	2.617	8.375-01
2.30-02			10.31	1.398		16.588	2.462	9.061-01
2.60-02			9.98	1.340		15.844	2.336	9.718-01
3.00-02			9.64	1.279		15.039	2.198	1.055+00
3.30-02			9.43	1.242		14.538	2.113	1.116+00
3.60-02			9.25	1.209		14.105	2.039	1.175+00
4.00-02			9.07	1.172		13.611	1.954	1.251+00
4.50-02			8.89	1.135		13.096	1.865	1.343+00
5.00-02			8.75	1.107		12.668	1.790	1.432+00
5.50-02			8.64	1.085		12.307	1.727	1.520+00
6.00-02			8.55	1.068		11.997	1.673	1.606+00
6.60-02			8.48	1.051		11.681	1.617	1.708+00
7.20-02			8.42	1.039		11.411	1.569	1.808+00
8.00-02			8.36	1.027		11.109	1.516	1.940+00
9.00-02			8.32	1.017		10.802	1.461	2.103+00
1.00-01			8.29	1.012		10.552	1.416	2.265+00
1.50-01			8.25	1.003		9.791	1.279	3.069+00
2.00-01			8.24	1.001		9.404	1.209	3.870+00
2.50-01			8.24	1.001		9.171	1.168	4.671+00
3.00-01			8.24	1.001		9.015	1.140	5.471+00
3.50-01			8.24	1.001		8.904	1.120	6.272+00
4.00-01			8.24	1.001		8.820	1.105	7.072+00
4.50-01			8.24	1.001		8.755	1.093	7.873+00
5.00-01			8.24	1.001		8.704	1.084	8.673+00
5.50-01			8.24	1.001		8.661	1.077	9.474+00
6.00-01			8.24	1.001		8.626	1.070	1.027+01
6.50-01			8.24	1.001		8.596	1.065	1.107+01

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .667, QPP.DH/K0.T0= -2.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.00	.942	34.68	5.262	.971	65.189	10.541	1.647-01
1.15-03	1.00	.938	32.57	4.898	.969	61.075	9.818	1.761-01
1.30-03	1.00	.935	30.85	4.634	.967	57.690	9.241	1.870-01
1.50-03	1.00	.931	28.97	4.267	.965	53.989	8.598	2.002-01
1.75-03	1.00	.926	27.08	3.955	.963	50.284	7.956	2.155-01
2.00-03	1.00	.921	25.54	3.703	.961	47.291	7.440	2.298-01
2.30-03	1.00	.916	24.05	3.455	.958	44.362	6.937	2.456-01
2.60-03	.99	.912	22.81	3.252	.956	41.951	6.524	2.603-01
3.00-03	.99	.906	21.47	3.057	.953	39.314	6.074	2.787-01
3.30-03	.99	.902	20.62	2.906	.951	37.658	5.796	2.917-01
3.60-03	.99	.898	19.82	2.766	.949	36.211	5.549	3.039-01
4.00-03	.99	.893	19.03	2.634	.947	34.540	5.266	3.193-01
4.50-03	.99	.888	18.14	2.494	.944	32.773	4.966	3.375-01
5.00-03	.99	.883	17.38	2.366	.942	31.277	4.715	3.547-01
5.50-03	.99	.878	16.73	2.258	.939	29.989	4.498	3.708-01
6.00-03	.99	.874	16.17	2.165	.937	28.865	4.309	3.862-01
6.60-03	.99	.869	15.57	2.064	.935	27.689	4.111	4.036-01
7.20-03	.99	.864	15.04	1.984	.932	26.663	3.939	4.202-01
8.00-03	.98	.858	14.47	1.878	.929	25.480	3.740	4.411-01
9.00-03	.98	.851	13.85	1.775	.926	24.230	3.530	4.653-01
1.00-02	.98	.845	13.33	1.687	.923	23.174	3.353	4.882-01
1.15-02	.98	.836	12.62	1.579	.919	21.858	3.131	5.197-01
1.30-02	.97	.828	12.17	1.494	.915	20.780	2.951	5.491-01
1.50-02	.97	.818	11.60	1.394	.910	19.605	2.754	5.849-01
1.75-02	.97	.807	11.05	1.300	.905	18.436	2.557	6.257-01
2.00-02	.96	.797	10.60	1.226	.901	17.497	2.400	6.628-01
2.30-02	.95	.787	10.19	1.153	.896	16.585	2.247	7.036-01
2.60-02	.95	.777	9.85	1.091	.891	15.841	2.123	7.409-01
3.00-02	.94	.765	9.50	1.027	.886	15.035	1.987	7.860-01
3.30-02	.93	.757	9.28	.989	.883	14.533	1.903	8.173-01
3.60-02	.93	.749	9.10	.953	.879	14.099	1.830	8.465-01
4.00-02	.92	.740	8.90	.909	.875	13.603	1.746	8.822-01
4.50-02	.91	.729	8.71	.868	.871	13.087	1.657	9.230-01
5.00-02	.90	.719	8.55	.835	.867	12.656	1.583	9.602-01
5.50-02	.89	.709	8.43	.807	.863	12.292	1.520	9.942-01
6.00-02	.88	.700	8.33	.782	.859	11.980	1.466	1.026+00
6.60-02	.87	.689	8.24	.757	.855	11.660	1.410	1.060+00
7.20-02	.86	.678	8.16	.735	.852	11.387	1.362	1.091+00
8.00-02	.84	.664	8.09	.709	.847	11.079	1.307	1.128+00
9.00-02	.82	.647	8.01	.681	.841	10.764	1.250	1.169+00

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .400, QPP.DH/KO.TO= 100.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.10	3.246	37.67	14.073	2.177	69.085	25.168	4.635-01
1.30-03	1.13	3.396	33.68	11.993	2.271	61.080	22.298	5.715-01
1.75-03	1.17	3.552	29.60	10.313	2.378	53.145	19.050	7.184-01
2.30-03	1.23	3.646	26.36	9.340	2.459	46.740	16.562	8.997-01
3.00-03	1.30	3.697	23.48	8.193	2.524	41.237	14.395	1.126+00
3.60-03	1.36	3.700	21.66	7.368	2.555	37.811	13.055	1.320+00
4.50-03	1.45	3.665	19.62	6.779	2.576	33.972	11.599	1.612+00
5.50-03	1.55	3.596	17.91	6.255	2.577	30.815	10.397	1.937+00
6.60-03	1.66	3.501	16.49	5.770	2.560	28.171	9.442	2.304+00
8.00-03	1.80	3.367	15.11	5.445	2.522	25.593	8.533	2.781+00
1.00-02	2.00	3.173	13.67	4.989	2.452	22.873	7.625	3.485+00
1.30-02	2.30	2.907	12.23	4.549	2.329	20.006	6.714	4.610+00
1.75-02	2.75	2.564	10.90	4.020	2.146	17.194	5.839	6.447+00
2.30-02	3.30	2.238	10.00	3.425	1.950	15.015	5.109	8.913+00
3.00-02	4.00	1.941	9.39	2.811	1.753	13.272	4.411	1.232+01
3.60-02	4.60	1.759	9.12	2.416	1.623	12.284	3.931	1.545+01
4.50-02	5.50	1.570	8.89	2.020	1.482	11.290	3.373	2.049+01
5.50-02	6.50	1.432	8.74	1.734	1.375	10.575	2.918	2.662+01
6.60-02	7.60	1.333	8.63	1.547	1.294	10.049	2.559	3.410+01
8.00-02	9.00	1.251	8.53	1.415	1.226	9.598	2.246	4.498+01
1.00-01	11.00	1.178	8.45	1.340	1.163	9.185	1.966	6.369+01
2.00-01	21.00	1.058	8.31	1.214	1.056	8.414	1.598	2.474+02
3.00-01	31.00	1.030	8.28	1.137	1.029	8.205	1.460	6.194+02
4.00-01	40.99	1.018	8.27	1.113	1.018	8.114	1.398	1.273+03
5.00-01	50.99	1.012	8.26	1.119	1.012	8.063	1.370	2.363+03
6.00-01	60.98	1.009	8.28	1.297	1.009	8.033	1.367	4.291+03

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .400, QPP.DH/K0.T0= 10.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DREO	TB/TI	TW/TB	NUBX	FRB/24	WA/PA	NUBA	FRBA/24	PO-PI
1.00-03	1.01	1.267	36.84	8.607	1.134	60.301	15.603	1.715-01
1.30-03	1.01	1.298	32.77	7.688	1.150	61.290	13.875	2.016-01
1.75-03	1.02	1.337	28.78	6.804	1.170	53.377	12.135	2.425-01
2.30-03	1.02	1.376	25.58	6.048	1.190	47.051	10.744	2.887-01
3.00-03	1.03	1.416	22.85	5.482	1.211	41.660	9.545	3.429-01
3.60-03	1.04	1.444	21.16	5.039	1.226	38.343	8.813	3.871-01
4.50-03	1.04	1.479	19.33	4.620	1.245	34.667	7.989	4.498-01
5.50-03	1.06	1.510	17.84	4.247	1.262	31.639	7.317	5.164-01
6.60-03	1.07	1.538	16.61	3.942	1.278	29.226	6.753	5.863-01
8.00-03	1.08	1.566	15.45	3.663	1.294	26.857	6.207	6.721-01
1.00-02	1.10	1.594	14.24	3.356	1.311	24.379	5.629	7.905-01
1.30-02	1.13	1.621	13.06	3.048	1.330	21.800	5.021	9.621-01
1.75-02	1.17	1.639	11.86	2.743	1.345	19.262	4.415	1.212+00
2.30-02	1.23	1.640	10.88	2.497	1.353	17.247	3.927	1.514+00
3.00-02	1.30	1.623	10.14	2.285	1.352	15.546	3.509	1.897+00
3.60-02	1.36	1.600	9.72	2.150	1.346	14.517	3.250	2.228+00
4.50-02	1.45	1.560	9.33	2.003	1.331	13.400	2.962	2.735+00
5.50-02	1.55	1.513	9.06	1.875	1.312	12.526	2.727	3.317+00
6.60-02	1.66	1.463	8.89	1.770	1.289	11.833	2.532	3.981+00
8.00-02	1.80	1.408	8.76	1.667	1.262	11.203	2.344	4.869+00
1.00-01	2.00	1.343	8.64	1.569	1.229	10.589	2.147	6.229+00
2.00-01	3.00	1.173	8.44	1.335	1.130	9.290	1.721	1.529+01
3.00-01	4.00	1.106	8.36	1.215	1.085	8.837	1.535	2.853+01
4.00-01	5.00	1.072	8.33	1.157	1.060	8.607	1.438	4.717+01
5.00-01	6.00	1.052	8.31	1.125	1.045	8.468	1.382	7.257+01
6.00-01	7.00	1.040	8.32	1.106	1.035	8.375	1.347	1.063+02

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR.0= .400, QPP.DH/K0.T0= 100.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .000,CON= .000,CP= .000

4X/DPEC	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03			36.89	7.122		69.499	13.878	1.332-01
1.15-03			34.64	6.535		65.099	12.957	1.430-01
1.30-03			32.77	6.166		61.476	12.184	1.521-01
1.50-03			30.75	5.840		57.513	11.365	1.637-01
1.75-03			28.73	5.383		53.545	10.539	1.771-01
2.00-03			27.08	5.062		50.340	9.870	1.895-01
2.30-03			25.48	4.750		47.202	9.224	2.037-01
2.60-03			24.16	4.448		44.619	8.698	2.169-01
3.00-03			22.72	4.180		41.795	8.099	2.333-01
3.30-03			21.91	4.045		40.020	7.737	2.451-01
3.60-03			21.02	3.849		38.469	7.424	2.566-01
4.00-03			20.10	3.617		36.678	7.049	2.707-01
4.50-03			19.15	3.448		34.783	6.659	2.877-01
5.00-03			18.34	3.289		33.179	6.329	3.038-01
5.50-03			17.64	3.160		31.798	6.046	3.193-01
6.00-03			17.03	3.029		30.593	5.801	3.341-01
6.60-03			16.40	2.899		29.331	5.541	3.511-01
7.20-03			15.85	2.780		28.231	5.317	3.675-01
8.00-03			15.22	2.637		26.961	5.054	3.881-01
9.00-03			14.56	2.511		25.620	4.779	4.129-01
1.00-02			14.01	2.392		24.487	4.545	4.363-01
1.15-02			13.32	2.252		23.075	4.254	4.697-01
1.30-02			12.77	2.140		21.918	4.016	5.012-01
1.50-02			12.17	2.012		20.658	3.757	5.410-01
1.75-02			11.58	1.888		19.402	3.497	5.875-01
2.00-02			11.11	1.792		18.395	3.290	6.316-01
2.30-02			10.66	1.693		17.415	3.087	6.816-01
2.60-02			10.30	1.614		16.614	2.921	7.291-01
3.00-02			9.93	1.533		15.747	2.741	7.893-01
3.30-02			9.70	1.482		15.208	2.629	8.327-01
3.60-02			9.50	1.433		14.740	2.531	8.747-01
4.00-02			9.29	1.378		14.206	2.418	9.285-01
4.50-02			9.09	1.323		13.649	2.299	9.932-01
5.00-02			8.93	1.278		13.185	2.199	1.056+00
5.50-02			8.80	1.240		12.792	2.113	1.116+00
6.00-02			8.70	1.208		12.455	2.039	1.175+00
6.60-02			8.60	1.175		12.109	1.962	1.243+00
7.20-02			8.53	1.147		11.814	1.895	1.310+00
8.00-02			8.45	1.117		11.482	1.819	1.397+00
9.00-02			8.39	1.089		11.142	1.739	1.503+00
1.00-01			8.35	1.069		10.865	1.673	1.606+00
1.50-01			8.27	1.022		10.013	1.460	2.102+00
2.00-01			8.25	1.007		9.574	1.347	2.587+00
2.50-01			8.24	1.003		9.308	1.279	3.069+00
3.00-01			8.24	1.001		9.130	1.233	3.550+00
3.50-01			8.24	1.001		9.002	1.199	4.030+00
4.00-01			8.24	1.001		8.907	1.175	4.510+00
4.50-01			8.24	1.001		8.832	1.155	4.991+00
5.00-01			8.24	1.001		8.773	1.140	5.471+00
5.50-01			8.24	1.001		8.724	1.127	5.951+00
6.00-01			8.24	1.001		8.684	1.117	6.432+00
6.50-01			8.24	1.001		8.649	1.108	6.912+00

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR.O= .200, QPP.DH/KO.TO= 100.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	MA/BA	NUBA	FRBA/24	K
1.00-03	1.10	3.120	40.10	19.542	2.109	74.157	34.261	.258
1.30-03	1.13	3.265	35.80	16.946	2.200	65.471	30.206	.310
1.75-03	1.17	3.410	31.45	13.839	2.300	56.878	25.992	.381
2.30-03	1.23	3.504	27.91	11.789	2.380	49.944	22.394	.460
3.00-03	1.30	3.562	24.76	9.692	2.447	43.987	19.104	.548
3.60-03	1.36	3.568	22.80	8.716	2.479	40.273	17.132	.619
4.50-03	1.45	3.540	20.59	7.926	2.503	36.115	14.914	.716
5.50-03	1.55	3.475	18.78	7.372	2.504	32.700	13.222	.817
6.60-03	1.66	3.394	17.24	6.688	2.493	29.854	11.831	.920
8.00-03	1.80	3.265	15.79	6.503	2.456	27.069	10.605	1.045
1.00-02	2.00	3.085	14.26	6.045	2.390	24.139	9.405	1.212
1.30-02	2.30	2.832	12.72	5.716	2.276	21.071	8.279	1.445
1.75-02	2.75	2.504	11.33	5.181	2.103	18.061	7.274	1.771
2.30-02	3.30	2.192	10.39	4.506	1.915	15.736	6.460	2.128
3.00-02	4.00	1.905	9.77	3.705	1.724	13.886	5.655	2.510
3.60-02	4.60	1.728	9.50	3.161	1.598	12.841	5.068	2.774
4.50-02	5.50	1.547	9.27	2.610	1.462	11.794	4.360	3.087
5.50-02	6.50	1.416	9.08	2.203	1.361	11.038	3.764	3.351
6.60-02	7.60	1.322	8.92	1.915	1.285	10.473	3.279	3.570
8.00-02	9.00	1.244	8.76	1.687	1.220	9.975	2.836	3.781
1.00-01	11.00	1.175	8.61	1.526	1.160	9.505	2.418	4.003
2.00-01	21.00	1.058	8.36	1.266	1.055	8.581	1.764	5.248
3.00-01	31.00	1.030	8.31	1.158	1.029	8.308	1.545	6.175
4.00-01	40.99	1.018	8.28	1.116	1.018	8.186	1.447	7.367
5.00-01	50.99	1.012	8.25	1.097	1.012	8.116	1.397	9.286
6.00-01	60.98	1.009	8.28	1.094	1.009	8.072	1.368	12.607

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .200, QPP.DH/KO.TO= 50.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	K
1.00-03	1.05	2.152	39.84	17.196	1.590	74.627	29.429	.188
2.00-03	1.10	2.437	29.45	12.322	1.753	53.831	21.622	.301
3.60-03	1.18	2.636	22.87	8.984	1.886	40.889	16.240	.446
6.00-03	1.30	2.715	18.42	7.002	1.969	32.182	12.438	.627
1.00-02	1.50	2.652	14.89	5.674	1.991	25.283	9.477	.881
2.00-02	2.00	2.301	11.42	4.508	1.867	18.194	6.705	1.407
3.60-02	2.80	1.844	9.77	3.396	1.622	13.960	5.072	2.076
6.00-02	4.00	1.482	9.17	2.384	1.385	11.546	3.801	2.769
1.00-01	6.00	1.248	8.77	1.741	1.212	10.050	2.734	3.452
3.50-01	18.50	1.036	8.35	1.245	1.034	8.411	1.605	7.107

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .200, QPP.DH/KO.TO= 25.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	K
1.00-03	1.03	1.602	39.80	14.757	1.305	75.001	25.273	.142
2.00-03	1.05	1.784	29.29	10.987	1.401	54.144	18.782	.223
3.60-03	1.09	1.945	22.75	8.359	1.493	41.212	14.456	.326
6.00-03	1.15	2.062	18.44	6.570	1.568	32.591	11.407	.456
1.00-02	1.25	2.121	15.09	5.240	1.623	25.843	8.914	.637
2.00-02	1.50	2.044	11.77	4.019	1.627	18.977	6.359	1.008
3.60-02	1.90	1.813	10.00	3.213	1.532	14.787	4.814	1.488
6.00-02	2.50	1.543	9.27	2.504	1.388	12.234	3.759	2.052
1.00-01	3.50	1.314	8.89	1.908	1.244	10.565	2.867	2.709
3.50-01	9.75	1.056	8.37	1.218	1.050	8.612	1.640	4.868

Inlet pressure was relatively low on these two calculations, leading to Mach number greater than 0.2 for $x^* > 0.3$.

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,O= .200, QPP.DH/KO.TO= 10.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEO	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.01	1.246	39.89	12.320	1.124	75.346	21.958	1.266-01
1.30-03	1.01	1.276	35.41	10.974	1.139	64.591	19.518	1.495-01
1.75-03	1.02	1.313	31.07	9.607	1.158	57.935	17.107	1.813-01
2.30-03	1.02	1.350	27.49	8.633	1.177	51.009	15.152	2.171-01
3.00-03	1.03	1.388	24.50	7.628	1.197	45.105	13.465	2.596-01
3.60-03	1.04	1.415	22.64	7.089	1.211	41.470	12.418	2.940-01
4.50-03	1.05	1.449	20.67	6.368	1.229	37.441	11.243	3.433-01
5.50-03	1.06	1.479	18.99	5.895	1.246	34.176	10.276	3.954-01
6.60-03	1.07	1.507	17.65	5.403	1.261	31.477	9.464	4.503-01
8.00-03	1.08	1.534	16.37	4.980	1.277	28.880	8.676	5.181-01
1.00-02	1.10	1.562	15.06	4.519	1.294	26.165	7.835	6.111-01
1.30-02	1.13	1.589	13.70	4.056	1.313	23.340	6.944	7.456-01
1.75-02	1.17	1.608	12.40	3.602	1.329	20.561	6.056	9.415-01
2.30-02	1.23	1.611	11.39	3.244	1.337	18.355	5.340	1.176+00
3.00-02	1.30	1.597	10.58	2.937	1.337	16.496	4.727	1.474+00
3.60-02	1.36	1.576	10.13	2.753	1.332	15.369	4.348	1.729+00
4.50-02	1.45	1.538	9.69	2.546	1.319	14.148	3.930	2.118+00
5.50-02	1.55	1.494	9.40	2.371	1.300	13.191	3.591	2.560+00
6.60-02	1.66	1.447	9.21	2.223	1.279	12.434	3.310	3.060+00
8.00-02	1.80	1.395	9.06	2.077	1.254	11.742	3.040	3.721+00
1.00-01	2.00	1.333	8.93	1.925	1.222	11.066	2.757	4.716+00
2.00-01	3.00	1.170	8.60	1.514	1.128	9.608	2.088	1.085+01
3.00-01	4.00	1.104	8.46	1.319	1.084	9.071	1.782	1.903+01
4.00-01	5.00	1.071	8.40	1.225	1.059	8.787	1.615	2.983+01
5.00-01	6.00	1.052	8.36	1.172	1.045	8.612	1.515	4.384+01
6.00-01	7.00	1.040	8.33	1.140	1.035	8.493	1.450	6.168+01

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,O= .200, QPP.DH/KO.TO= 2.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEC	TB/TI	TW/TB	NUBX	FRB/24	FA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.00	1.050	40.02	10.401	1.025	75.594	19.912	9.996-02
1.30-03	1.00	1.056	35.51	9.147	1.028	64.832	17.585	1.154-01
1.75-03	1.00	1.064	31.06	8.065	1.032	58.165	15.259	1.358-01
2.30-03	1.00	1.072	27.50	7.060	1.036	51.228	13.397	1.580-01
3.00-03	1.01	1.081	24.48	6.285	1.041	45.310	11.820	1.835-01
3.60-03	1.01	1.087	22.60	5.777	1.044	41.669	10.837	2.032-01
4.50-03	1.01	1.096	20.57	5.214	1.048	37.633	9.768	2.311-01
5.50-03	1.01	1.104	18.92	4.734	1.052	34.365	8.888	2.594-01
6.60-03	1.01	1.111	17.57	4.389	1.056	31.663	8.156	2.883-01
8.00-03	1.02	1.119	16.28	4.003	1.060	29.067	7.456	3.230-01
1.00-02	1.02	1.129	14.96	3.645	1.065	26.356	6.715	3.688-01
1.30-02	1.03	1.141	13.60	3.239	1.071	23.541	5.941	4.321-01
1.75-02	1.03	1.153	12.36	2.861	1.078	20.782	5.174	5.191-01
2.30-02	1.05	1.164	11.36	2.559	1.084	18.600	4.564	6.177-01
3.00-02	1.06	1.172	10.50	2.308	1.089	16.767	4.045	7.351-01
3.60-02	1.07	1.176	10.04	2.153	1.091	15.658	3.726	8.310-01
4.50-02	1.09	1.179	9.58	1.981	1.094	14.455	3.373	9.695-01
5.50-02	1.11	1.180	9.27	1.849	1.095	13.509	3.088	1.118+00
6.60-02	1.13	1.178	9.05	1.743	1.094	12.754	2.853	1.278+00
8.00-02	1.16	1.174	8.88	1.647	1.093	12.058	2.629	1.479+00
1.00-01	1.20	1.166	8.74	1.559	1.091	11.370	2.397	1.765+00
2.00-01	1.40	1.130	8.54	1.370	1.076	9.902	1.862	3.272+00
3.00-01	1.60	1.104	8.46	1.283	1.064	9.369	1.644	4.972+00
4.00-01	1.80	1.085	8.42	1.230	1.055	9.087	1.523	6.913+00
5.00-01	2.00	1.071	8.39	1.193	1.047	8.910	1.446	9.126+00
6.00-01	2.20	1.060	8.37	1.165	1.041	8.787	1.393	1.163+01

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .200, QPP,DH/K0,T0= 100.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .000,CON= .000,CP= .000

4X/DPE0	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24
1.00-03			40.07	10.280		75.657	19.417
1.15-03			37.59	9.298		70.853	18.118
1.30-03			35.54	8.847		66.897	17.082
1.50-03			33.37	8.167		62.568	15.933
1.75-03			31.09	7.566		58.230	14.771
2.00-03			29.28	7.108		54.725	13.841
2.30-03			27.52	6.639		51.291	12.928
2.60-03			26.07	6.213		48.465	12.179
3.00-03			24.47	5.916		45.373	11.343
3.30-03			23.47	5.688		43.429	10.850
3.60-03			22.62	5.353		41.731	10.401
4.00-03			21.62	5.093		39.770	9.882
4.50-03			20.57	4.768		37.695	9.333
5.00-03			19.60	4.535		35.937	8.859
5.50-03			18.91	4.384		34.424	8.461
6.00-03			18.25	4.211		33.104	8.113
6.60-03			17.56	4.032		31.722	7.750
7.20-03			16.95	3.830		30.516	7.433
8.00-03			16.24	3.615		29.125	7.057
9.00-03			15.54	3.451		27.656	6.667
1.00-02			14.93	3.283		26.413	6.336
1.15-02			14.18	3.076		24.866	5.924
1.30-02			13.56	2.896		23.598	5.583
1.50-02			12.90	2.714		22.216	5.211
1.75-02			12.25	2.535		20.839	4.840
2.00-02			11.73	2.395		19.733	4.542
2.30-02			11.24	2.260		18.657	4.253
2.60-02			10.84	2.142		17.778	4.015
3.00-02			10.42	2.019		16.826	3.756
3.30-02			10.17	1.945		16.232	3.595
3.60-02			9.95	1.879		15.718	3.454
4.00-02			9.72	1.796		15.129	3.293
4.50-02			9.48	1.709		14.515	3.121
5.00-02			9.29	1.641		14.002	2.976
5.50-02			9.14	1.584		13.567	2.852
6.00-02			9.02	1.533		13.193	2.744
6.60-02			8.90	1.478		12.809	2.631
7.20-02			8.81	1.432		12.479	2.533
8.00-02			8.71	1.377		12.107	2.420
9.00-02			8.62	1.322		11.725	2.301
1.00-01			8.55	1.278		11.411	2.200
1.50-01			8.40	1.140		10.432	1.861
2.00-01			8.32	1.074		9.915	1.670
2.50-01			8.28	1.039		9.592	1.546
3.00-01			8.26	1.021		9.371	1.460
3.50-01			8.25	1.011		9.212	1.396
4.00-01			8.24	1.006		9.091	1.348
4.50-01			8.24	1.004		8.997	1.310
5.00-01			8.24	1.002		8.921	1.279
5.50-01			8.24	1.002		8.859	1.254
6.00-01			8.24	1.001		8.807	1.233
6.50-01			8.24	1.001		8.764	1.215

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .200, QPP.DH/K0.T0= -.2, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPEU	TB/TI	TW/TB	NUPX	FPB/24	WA/BA	NUBA	FPBA/24	PO-PI
1.00-03	1.00	.995	40.04	9.807	.998	75.494	19.349	9.265-02
1.30-03	1.00	.994	35.63	8.706	.997	66.787	17.029	1.059-01
1.75-03	1.00	.994	31.07	7.566	.997	58.155	14.708	1.231-01
2.30-03	1.00	.993	27.60	6.627	.996	51.240	12.875	1.414-01
3.00-03	1.00	.992	24.52	5.787	.996	45.351	11.306	1.618-01
3.60-03	1.00	.991	22.66	5.309	.996	41.720	10.350	1.776-01
4.50-03	1.00	.990	20.61	4.777	.995	37.689	9.281	1.989-01
5.50-03	1.00	.989	18.91	4.355	.995	34.425	8.421	2.204-01
6.60-03	1.00	.989	17.56	3.965	.994	31.729	7.706	2.417-01
8.00-03	1.00	.988	16.26	3.592	.994	29.132	7.021	2.666-01
1.00-02	1.00	.987	14.94	3.225	.993	26.426	6.293	2.982-01
1.30-02	1.00	.985	13.57	2.871	.993	23.611	5.543	3.406-01
1.75-02	1.00	.984	12.24	2.502	.992	20.850	4.804	3.962-01
2.30-02	1.00	.982	11.23	2.223	.991	18.607	4.219	4.557-01
3.00-02	.99	.981	10.40	1.983	.990	16.834	3.724	5.227-01
3.60-02	.99	.980	9.95	1.844	.990	15.725	3.424	5.748-01
4.50-02	.99	.979	9.46	1.678	.989	14.521	3.091	6.459-01
5.50-02	.99	.978	9.12	1.550	.989	13.573	2.824	7.180-01
6.60-02	.99	.977	8.88	1.445	.989	12.814	2.604	7.910-01
8.00-02	.98	.976	8.68	1.343	.988	12.111	2.394	8.767-01
1.00-01	.98	.976	8.52	1.242	.988	11.413	2.176	9.887-01
2.00-01	.96	.974	8.27	1.023	.987	9.910	1.645	1.448+00
3.00-01	.94	.973	8.21	.962	.987	9.360	1.435	1.841+00

LAMINAR GAS FLOW BETWEEN PARALLEL PLATES

SYMMETRIC CONSTANT WALL HEAT FLUX

PR,0= .200, QPP.DH/K0.T0= -2.0, GAMMA=1.667

PROPERTY EXPONENTS, VIS= .750,CON= .750,CP= .000

4X/DPED	TB/TI	TW/TB	NUBX	FRB/24	WA/BA	NUBA	FRBA/24	PO-PI
1.00-03	1.00	.950	40.11	9.455	.975	75.714	18.807	8.629-02
1.15-03	1.00	.947	37.63	8.824	.973	70.912	17.554	9.229-02
1.30-03	1.00	.944	35.57	8.226	.972	66.956	16.507	9.779-02
1.50-03	1.00	.940	33.35	7.642	.970	62.627	15.364	1.045-01
1.75-03	1.00	.935	31.12	7.081	.968	58.290	14.215	1.123-01
2.00-03	1.00	.931	29.31	6.668	.966	54.785	13.299	1.195-01
2.30-03	1.00	.927	27.54	6.213	.963	51.352	12.407	1.275-01
2.60-03	.99	.923	26.09	5.796	.961	48.526	11.669	1.348-01
3.00-03	.99	.918	24.51	5.412	.959	45.435	10.855	1.438-01
3.30-03	.99	.914	23.51	5.164	.957	43.491	10.355	1.502-01
3.60-03	.99	.910	22.62	4.870	.955	41.793	9.912	1.562-01
4.00-03	.99	.906	21.62	4.584	.953	39.832	9.393	1.634-01
4.50-03	.99	.901	20.57	4.314	.951	37.756	8.848	1.720-01
5.00-03	.99	.897	19.68	4.142	.949	35.999	8.384	1.799-01
5.50-03	.99	.892	18.92	3.953	.946	34.487	7.999	1.875-01
6.00-03	.99	.888	18.24	3.698	.944	33.167	7.652	1.945-01
6.60-03	.99	.883	17.55	3.541	.942	31.785	7.286	2.021-01
7.20-03	.99	.879	16.94	3.385	.940	30.579	6.974	2.096-01
8.00-03	.98	.873	16.25	3.177	.937	29.189	6.605	2.185-01
9.00-03	.98	.867	15.52	3.002	.934	27.719	6.221	2.290-01
1.00-02	.98	.861	14.90	2.832	.931	26.476	5.895	2.385-01
1.15-02	.98	.853	14.15	2.637	.927	24.929	5.490	2.514-01
1.30-02	.97	.845	13.52	2.467	.924	23.660	5.156	2.630-01
1.50-02	.97	.836	12.85	2.292	.919	22.278	4.793	2.767-01
1.75-02	.96	.825	12.20	2.120	.914	20.900	4.432	2.916-01
2.00-02	.96	.816	11.67	1.972	.910	19.794	4.143	3.045-01
2.30-02	.95	.805	11.16	1.828	.905	18.718	3.859	3.177-01
2.60-02	.95	.796	10.75	1.716	.901	17.838	3.628	3.291-01
3.00-02	.94	.784	10.32	1.597	.895	16.884	3.376	3.416-01
3.30-02	.93	.776	10.05	1.529	.892	16.289	3.220	3.497-01
3.60-02	.93	.768	9.82	1.454	.888	15.773	3.085	3.568-01
4.00-02	.92	.758	9.56	1.360	.884	15.182	2.928	3.641-01
4.50-02	.91	.747	9.31	1.276	.879	14.563	2.762	3.711-01
5.00-02	.90	.736	9.10	1.206	.875	14.046	2.622	3.760-01
5.50-02	.89	.725	8.92	1.139	.871	13.606	2.503	3.792-01
6.00-02	.88	.715	8.77	1.078	.867	13.227	2.398	3.807-01
6.60-02	.87	.703	8.63	1.017	.862	12.835	2.290	3.804-01
7.20-02	.86	.691	8.50	.956	.858	12.497	2.195	3.784-01
8.00-02	.84	.675	8.36	.879	.852	12.114	2.085	3.727-01
9.00-02	.82	.655	8.21	.792	.845	11.715	1.968	3.615-01

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